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OPERATION TUMBLER

Project 1.9

PRE-SHOCK DUST

REPORT TO THE TEST DIRECTOR

by

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October 1952

Chemical Corps
Chemical and Radiological Laboratories
Army Chemical Center

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ABSTRACT

The objective of Project 1.9 was to determine the concentration and the particle size distribution of the pre-shock dust generated from the surface of the ground by air currents resulting from the incidence of thermal radiation on the surface of the ground.

Cascade impactors and filter samplers were used to sample pre-shock dust for the brief period of time between the time of detonation and the arrival of the shock wave at the station.

The following conclusions are drawn:

1. The presence of pre-shock dust in concentration of from ten to several hundred times background has been established.

2. There was no significant difference between the particle size distribution of pre-shock dust and background dust.

3. Little variation in dust concentrations from shot to shot was shown.

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ACKNOWLEDGEMENTS

The project officer wishes to express his appreciation to the personnel in Radiological Division, Chemical and Radiological Laboratories, who assisted in the successful prosecution of this project.

Acknowledgement is also made for the services of M. C. Armacost, L. Totaro, and Pfc B. Jackson for their help in the design of towers and equipment; J. D. Wilcox, W. R. Van Antwerp, Pfc H. N. Beck, and Pfc D. L. Rigotti for their assistance in preparing and analyzing the cascade impactor and molecular filter samples.

Much of the draft copy of this report as submitted by the authors has been revised by Dr. F. A. Hedman of the Radiological Division Publication Writers Group of the Chemical Corps Chemical and Radiological Laboratories.

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CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

The primary objective of Operation TUMBLER was to determine the extent of the loss of theoretical peak overpressure measured on the ground from an atomic bomb detonation and to develop scaling laws for determining the optimum height for such detonations.

The objective of Project 1.9 was to determine the concentration and the particle size distribution of the pre-shock dust generated by the action of thermal radiation on the surface of the ground.

These data will be applied to the determination of the effects of thermal radiation on the loss of theoretical overpressure.

1.2 BACKGROUND

Overpressure results obtained at Operation BUSTER were 1/2 to 1/3 of the predicted values. It has been postulated that decay of the air shock wave is due to so-called mechanical and/or thermal effects. The loss of overpressure might be the result of the retarding effect of dust raised from the surface of the ground by thermal radiation. The resulting dust may absorb additional thermal energy and tend to magnify the loss of overpressure.

1.3 THEORY

1.3.1 Cascade Impactor

To determine the particle size distribution of any heterogeneous cloud a size-graded sampling method is desirable. Also to be desired is a minimum amount of physical strain on the particles as they are collected. The cascade impactor, first developed by May[1] is particularly suited to these requirements. The instrument used in these tests was a five-stage instrument designed at the Army Chemical Center[2,3,4,5] (Fig. 1.1). It deposits particles in five different size groups in a manner suitable for analysis with the light and/or the electron microscope. The larger particles, which are most likely to shatter, are collected at low velocities. The main disadvantage of the impactor is that it is not an absolute instrument, being that below a certain particle size, the probability of collection decreases in a rather complex manner.

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1.3.2 The Molecular Filter

Molecular filters (MF) consist of a loose network of cross-linked molecules of cellulose ester polymers, which appear as bright, white, smooth sheets. Detailed information may be found in Goetz' report.[6]

The effective pore size of an MF can be controlled during the manufacturing process. The pore size can be quite accurately controlled and varied over the range of 1 to 5,000 millimicrons. The pore openings on the influent side are smaller than on the effluent side so that there is a definite "screening action" rather than a "depth action" during filtration.

The cellulose esters used have high dielectric constants. Due to the large difference between the dielectric constants of the esters and air, passage of air through the filter gives a strong and lasting electrostatic charge to the filter. The retention of fine particles on the surface of a MF is believed to be due to these charges.

The molecular filter becomes almost completely transparent when placed in a clear liquid of refractive index of 1.49. The liquid used must not act as a solvent or a swelling agent. Particle deposits on the MF may then be examined optically. A porous plate or a wire mesh screen is necessary to support the MF during filtering operations.

1.3.3 Factors Influencing the Use of the Molecular Filter and the Cascade Impactor

The molecular filter in the sampler allowed a flow rate of 106 liters per minute to pass through a 100 cm^2 circular sampling area. However, the MF is fragile and it is not practical to analyze particles smaller than one micron with an optical system.

The cascade impactor separates particles into five size groupings which range from 100 microns to 0.1 micron. These groupings may be analyzed with optical and electron microscopes. The instrument however, has a flow rate of about 12.5 liters per minute, which is a disadvantage because of the short sampling time available on this project.

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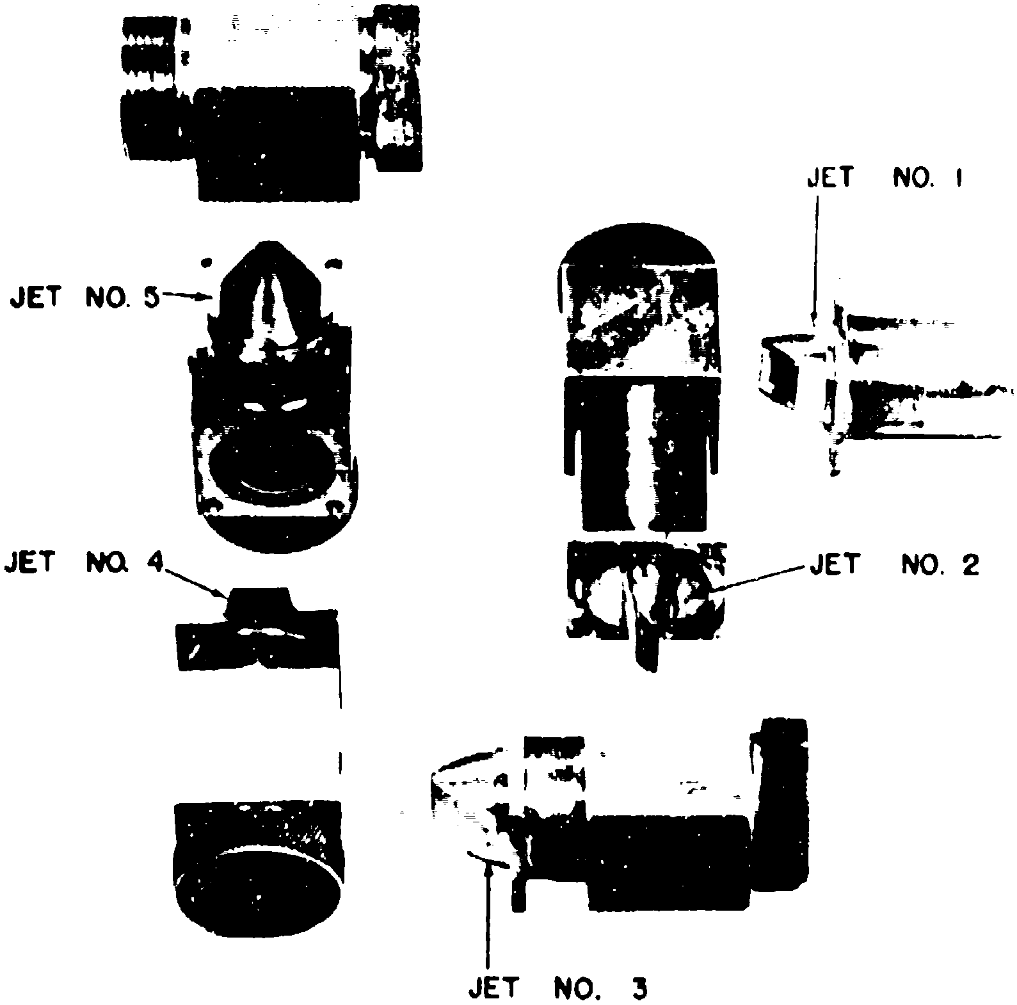

Fig. 1.1 Expanded V[illegible] of Cascade Impactor Jets

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CHAPTER 2

INSTRUMENTATION

2.1 DESIGN REQUIREMENTS

The sampling apparatus was designed to meet the following specifications:

1. A representative dust sample must be obtained.
2. The period of sampling must be limited to the interval between the time of detonation and the time of arrival of the shock wave.
3. The maximum percentage of the available cloud sample must go through the sampling apparatus.
4. The samplers must be easily removable from their mountings in order to minimize exposure of personnel to radiation.

2.2 DESCRIPTION

2.2.1 Cascade Impactor Sampler

The cascade impactor was connected by use of a tee to a solenoid valve and a filter (Chemical Corps Canister, Aerosol, E-12). The connecting pipe fittings were selected so as to have a minimum volume (see Sec. 2.1). A clamp was used to hold the cascade impactor inlet securely against a gasket (Fig. 2.1).

The valve was a Barksdale "Shear-seal" slide-type, quick-closing valve, spring loaded to the closed position. This valve allowed an essentially straight-line flow of dust samples to the samplers; the minimum flow passage diameter was 25/32 in., (Fig. 2.2).

The filter contains Chemical Corps Type 6 paper, which has a mean efficiency of 99.8 per cent when filtering the gross particulate contaminant existing in an atomic bomb cloud a few minutes after detonation.[7] Air cleaned by this filter swept the remaining dust samples out of the intake sampling line and on to the sampling surface. When the vacuum pump was operating with the solenoid valve closed, air, after passing through the filter, was drawn through the sampler. When the solenoid valve opened, all of the air was drawn through the valve inlet, because of the high resistance to air flow offered by the filter.

2.2.2 Filter Sampler

When using the molecular filter material, the filter sampler replaced the cascade impactor in the assembly shown in Fig. 2.1. The

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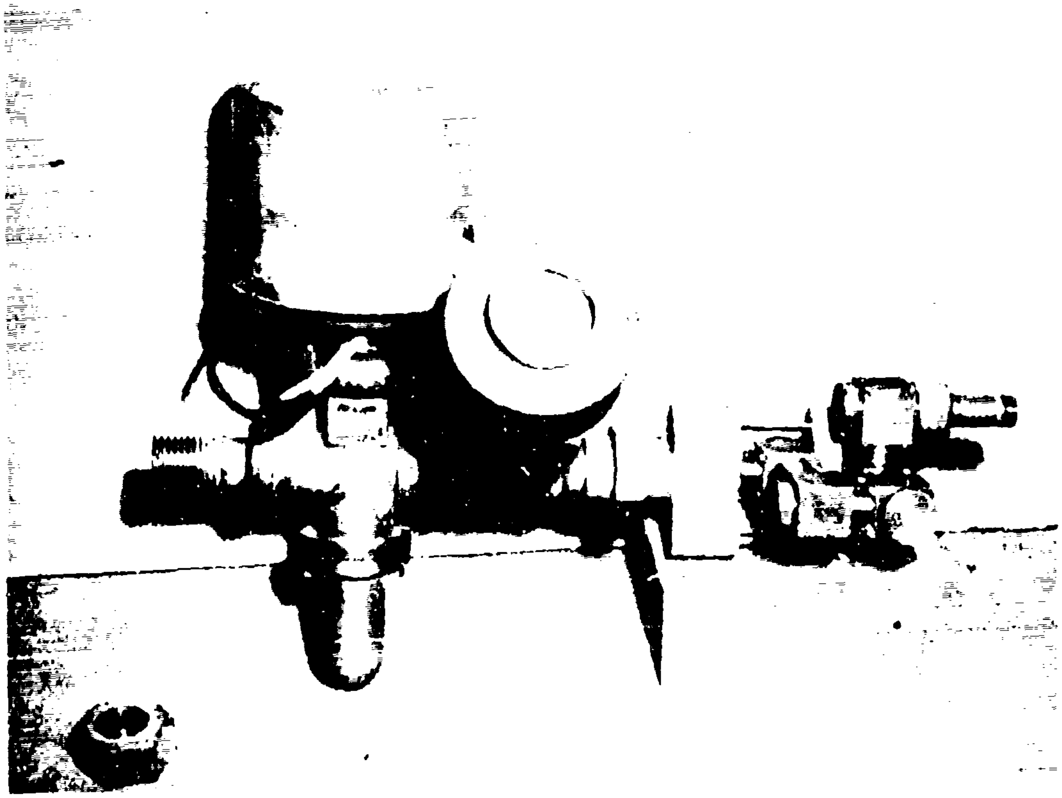

Fig.2.1 Cascade Impactor Sampler: Left to Right the Solenoid Valve, Filter, Connecting Clamp With the Impactor

effluent side of the sampler was connected to a vacumm pump (capacity is 4.8 cfm, at 20 inches of mercury). See Appendix C.

The molecular filter material used (Type HA, "Millipore") was made by the Lovell Chemical Co., Watertown, Mass., using the Goetz process.[6] This filter material was placed in a filter holder having "back-up" screens to support both sides of the filters during use. The sampling surface was a circular area of 100 sq. cm. (See Fig. 2.3.)

2.2.3 Control Circuit

The 110 volt power available at each sampling pit was brought in from a central power source by underground cables. The circuit (Fig. 2.4) was used to obtain properly controlled operation of the sampling equipment during the time interval between the arrival of the thermal wave and the arrival of the shock wave at each station. The

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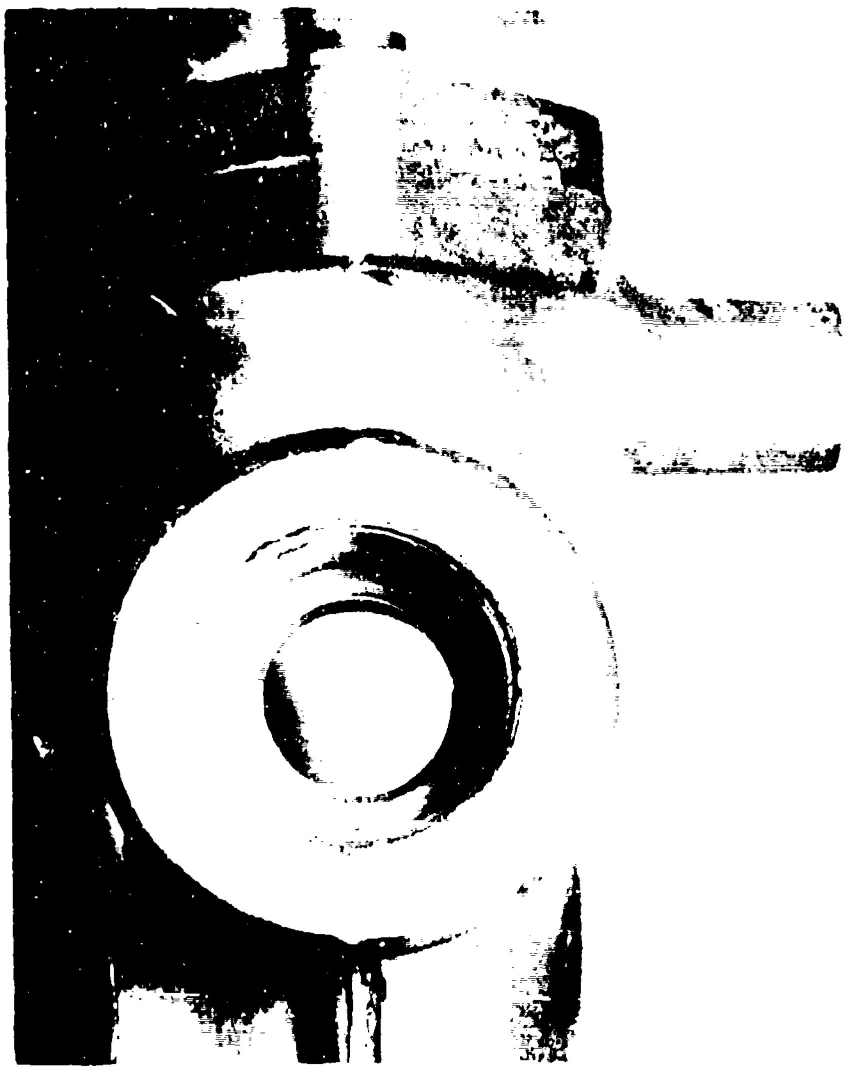

Fig. 2.2 Solenoid Valve Open. There Is No Obstruction to "Straight Through" Flow

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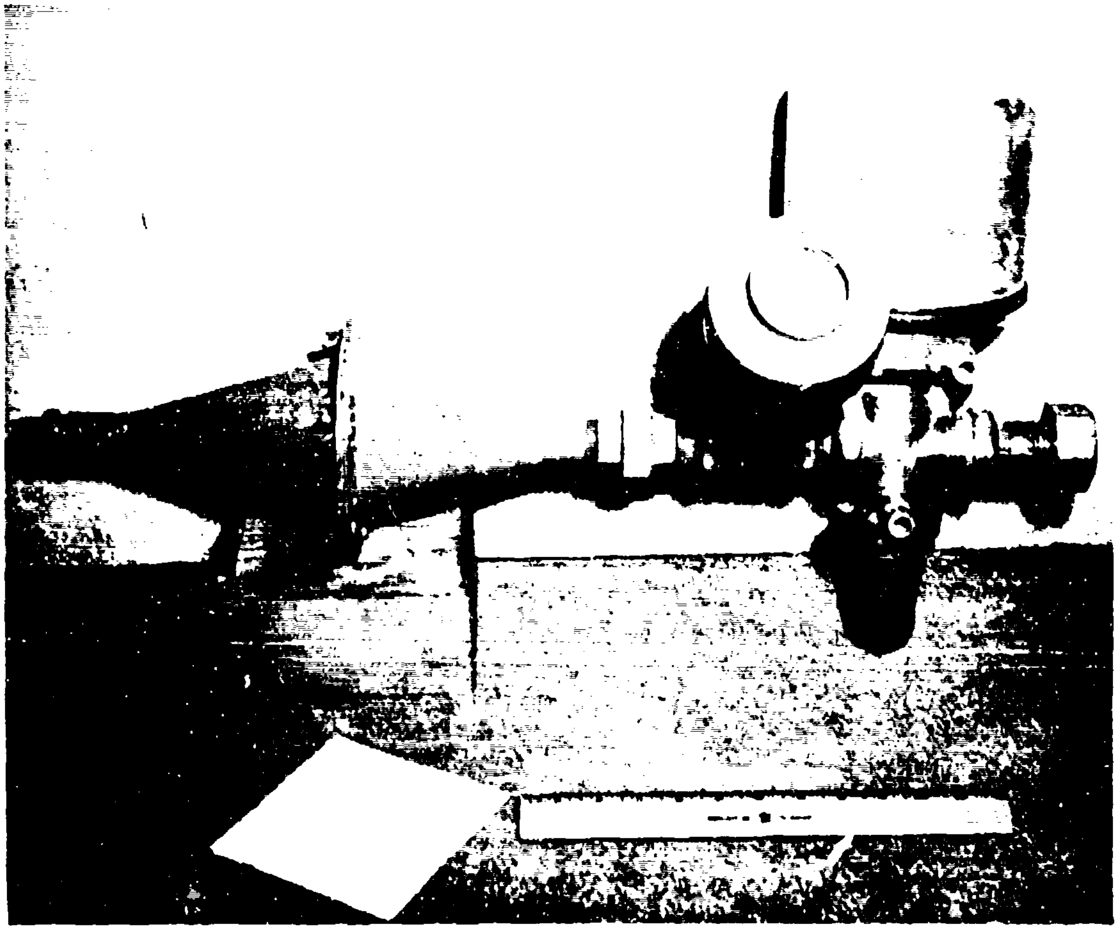

Fig. 2.3 The Filter Sampler, Aerosol Canister, and Solenoid Valve (A sheet of Molecular Filter Material is shown in the foreground)

coils of relays E_1 and E_2 of equipment supplied by Edgerton, Germeshausen, and Grier were activated by the arrival at the station of an electrical impulse.

The electrical impulse received by coil E_1 at H-15 second closed switch E_1, operating relay J_1 which closed switches J_{11} and J_{12}, thus starting the vacuum pump motors. A second signal was received by coil E_2 at H-2.5 seconds. This time interval of 12.5 seconds permitted the motors to attain rated speed conditions and attain rated vacuum on the samplers. Air was drawn through the aerosol canister and sampling lines during this period but since the valves were closed, the sample collecting devices received nc particulate matter.

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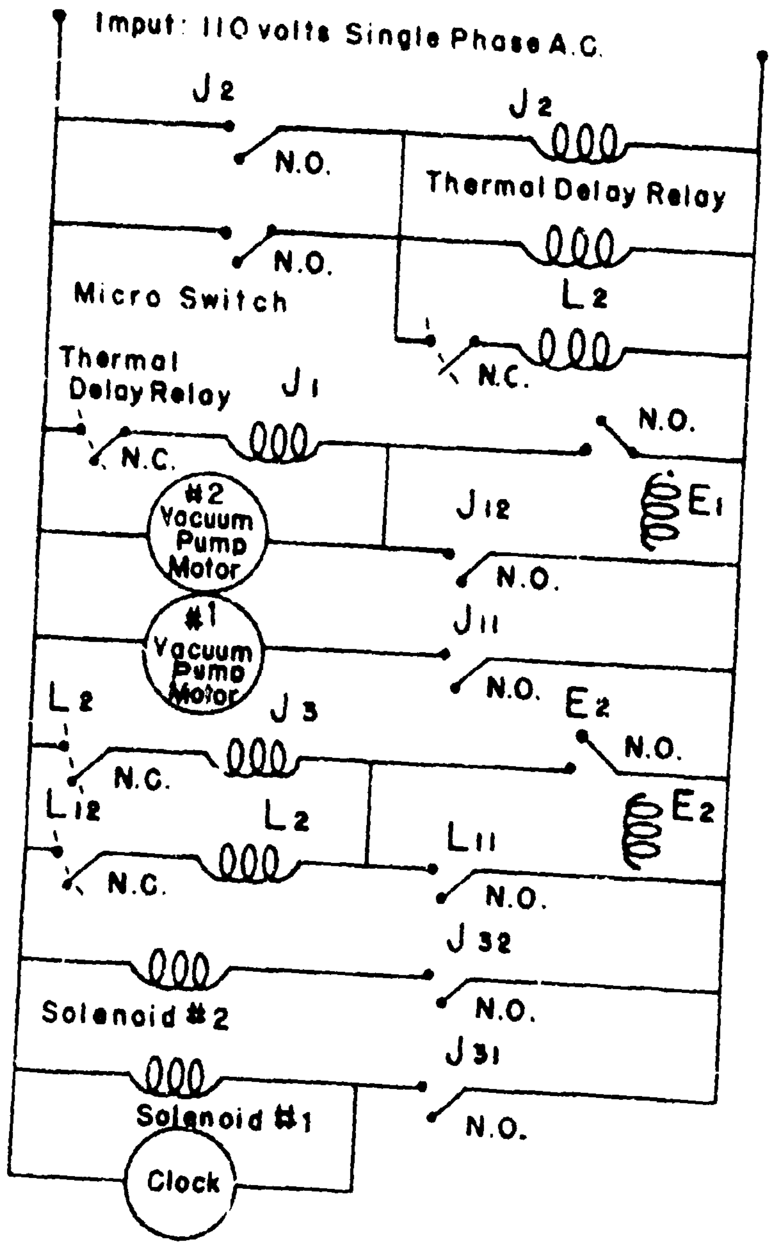

Fig. 2.4 Schematic Diagram of the Control Circuit

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The electrical impulse at H-2.5 seconds energized coil (E_2), closing switch (E_2), and energizing relay coil (J_3) which closed switches (J_{31}) and (J_{32}), thus opening the solenoid operated valves. This was the beginning of the sampling period which was recorded by the clock (C). This clock, having one second sweep hand, could be read to one thousandth of a second.

The blast-closure device (Fig. 2.5) was located a short distance toward ground zero from the sampling station. The exact location of this device was chosen so that the sampling would stop immediately prior to the arrival of the shock wave at the sampling ports.

The shock wave acting on the blast-closure device mechanically closed the micro switch, thus energizing the three parallel relay coils (J_2, the thermal delay relay, and L_2). Electrically locking relay J_2 insured operation after the micro switch had closed. Relay L_2 opened switch L_2, thus de-energizing the solenoid valves, stopping the clock, and ending the collection of samples. However, the thermal delay relay kept the vacuum pump in operation until the part of the sample still in the sampling lines had been transferred to the collecting surface. After a delay of seven seconds, the entire circuit was de-energized.

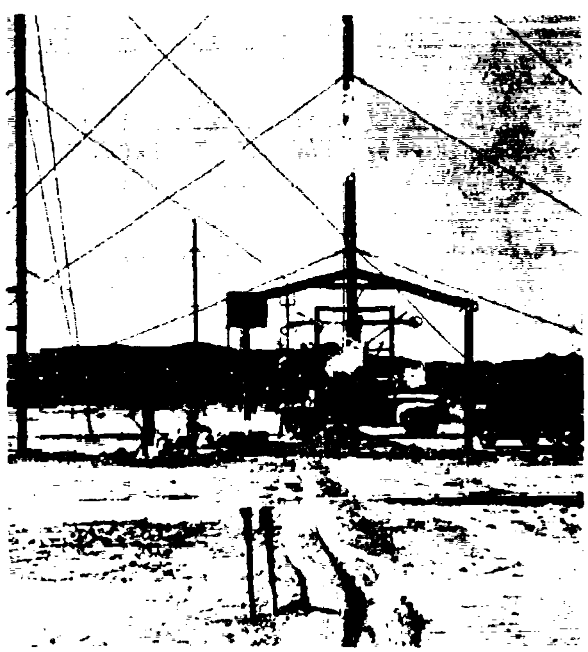

Fig. 2.5 Installation at Frenchman Flat F-202. The blast-closure microswitches are in the foreground. The ground and 10-ft. level boxes are to the left.

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2.3 STATION EQUIPMENT

For Shot 1 at Frenchman Flat, identical installations were made at ground and 10 ft. levels at stations F-202 and F-204. The samplers were mounted inside metal boxes (Fig. 2.6) so that samples entered through pipe nipples located in the box side six inches above the box bottom. The ground level samples were obtained by samplers in boxes which were bolted onto a concrete base, while the sample at the 10 ft. level was taken directly above the ground level sample (Fig. 2.8).

A wood-lined underground pit (Fig. 2.7), 10 ft. to the rear of the ground level sampler, contained the vacuum pumps, relays, and timing equipment.

Area 7 was used for Shots 2, 3, and 4. Three stations, 7-201, 7-202, and 7-204, were instrumented in this area. However, on Shot 3, station 7-201 was used for background measurements. At station 7-204, on Shot 4, an extra filter sampler was installed in the ground level box for background measurements. The stations in this area were 215 ft. east of the corresponding stations on the main blast line.

box at ground level in area 7 was mounted as at Frenchman Flat. However, the sampler collecting the 10 ft. level sample was in a box on top of a 7-ft. tower of the type used by the Chemical Corps in Operation JANGLE. The tower was mounted on a foundation extending one foot above ground level (Fig. 2.8).

Wires and tubing to the boxes were enclosed in iron pipe. All boxes were covered with aluminum sheeting to reflect part of the thermal wave.

2.4 FLOW CALIBRATION

The samplers (Molecular Filter and Cascade Impactor) were calibrated in the field, using a dry test meter.

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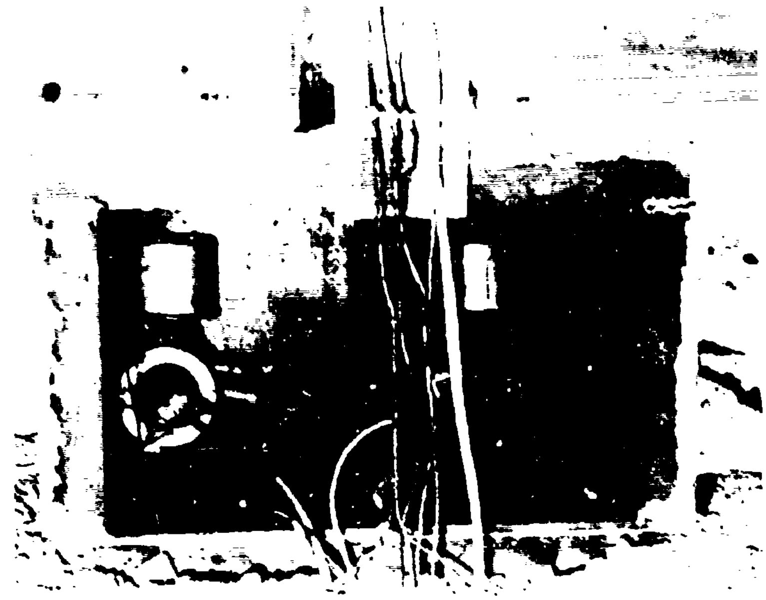

Fig. 2.6 F-202 Ground Level. View From Rear of Box

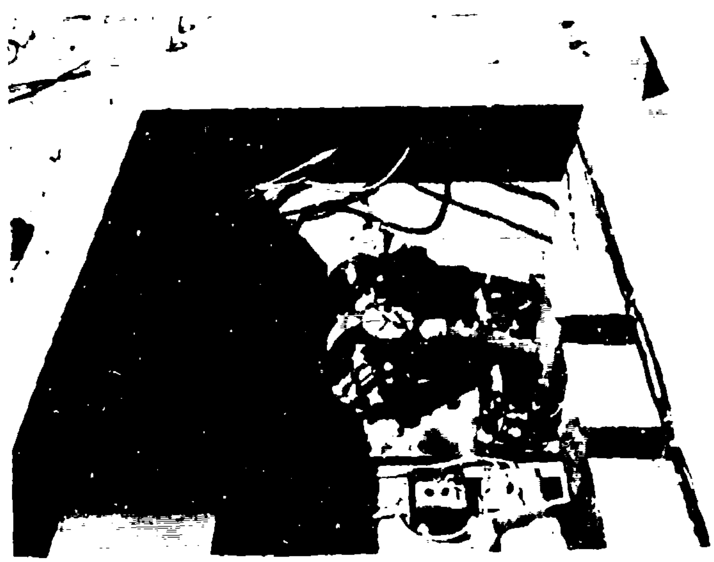

Fig. 2.7 Station 7-202. View of Underground Pit

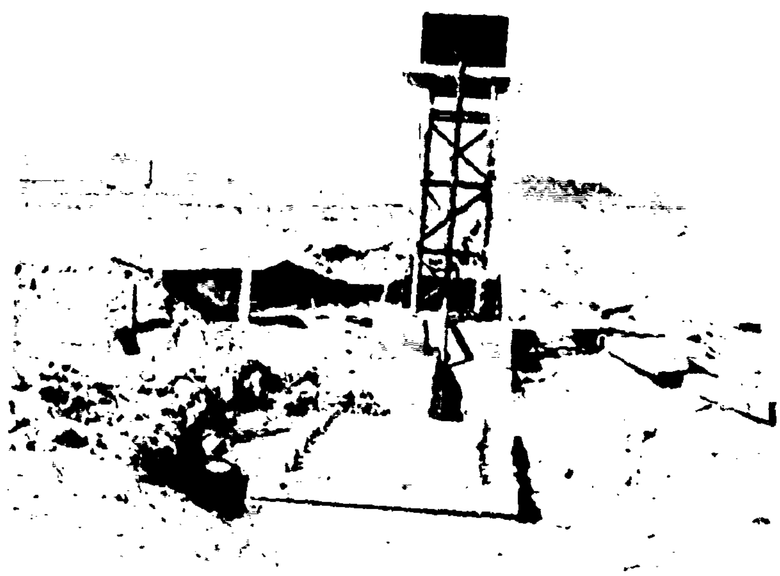

Fig. 2.8 Station 7-202 in Process of Construction Before Shot 2

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CHAPTER 3

TEST SITE OPERATIONS

3.1 DETONATION DETAILS

This series of tests was run as a portion of the study of the four atomic bomb detonations comprising Operation TUMBLER. A 1.05 kiloton bomb was detonated at 793 ft. elevation, at 0900 hrs., 1 April 1952; a 1.15 kiloton bomb at 1109 ft., at 0930 hrs., 15 April 1952; a 30 kiloton bomb at 3447 ft., at 0930 hrs., 22 April 1952; and a 19.6 kiloton bomb at 1040 ft., at 0830 hrs., 1 May 1952. All times given are Pacific Standard Time.

3.2 INSTALLATION OF SAMPLING EQUIPMENT

During the night before Shot 1, the ground around the blast line stations was thoroughly watered down. Particular care had been taken to see that ground was smoothed and hardened around the ground level boxes. This was not done on the last three shots in order that the area would be in approximately the same condition as it was during Operation BUSTER. The ground was mostly bare, ungraded, and loosely packed.

The cascade impactors used in this project were cleaned, assembled, and loaded with the plastic slides and electron microscope films at Army Chemical Center before shipment to the Nevada Proving Grounds. The ends of the cascade impactors were sealed to prevent contamination.

The filter samplers were loaded with the molecular filters at the site. The intakes and exhausts of all sampling equipment were sealed until they were actually mounted in the station boxes.

No impactors or filter samplers were actually installed at the stations until all timing signal "dry runs" had been completed.

After the first shot, a large amount of grease was noticed in the interior of the valves. Before each succeeding shot, the entire sampling train was cleaned with carbon tetrachloride or acetone. The inlets of the valves were then kept sealed until shortly before use.

Before each shot, the underground pits were covered with sandbags and dirt.

3.3 REMOVAL AND PACKING OF SAMPLING EQUIPMENT

The equipment was removed from the sampling stations as soon as

[redacted] [redacted]

permitted after each shot. Sampler intakes and exhausts were immediately sealed to prevent contamination.

At Yucca Flat Airstrip, the cascade impactors were placed in shipping boxes. Each molecular filter used with Shot 1 was put into a vinyl bag before being placed in a shipping box. All other used molecular filters were mounted on a rigid plastic plate, influent side out, and then packed and sealed in a dust free box. All operations in which the sampling surfaces were exposed to the atmosphere were performed in the closed cab of a truck. Within four hours after removal from the sampling station, each sample was placed aboard a courier plane and rushed to Army Chemical Center for study.

3.4 ANALYSIS AT ARMY CHEMICAL CENTER

3.4.1 Cascade Impactor Analysis

When exposed impactors were received from the test site they were monitored for radiation, and if safe were unloaded. The impaction areas of all jets were measured using scattered light. The first and second jet samples were examined, projected, and counted at 1,000X using a light microscope. The third and fourth jet samples were photographed using the electron microscope; the electron micrographs were then projected and counted at 10,000X. The fifth jet samples were photographed using the electron microscope; the electron micrographs were projected and counted at 50,000X. Heavy oil-like deposits and oversampling, combined with a large concentration of fibres, made the analysis of a few samples impossible.

3.4.2 Molecular Filter Analysis

One half of each filter was mounted on a clean, polished glass plate. Several drops of acetone were placed, at random spots, on the filter dissolving small areas of the filter. This treatment left the particulate material in an ideal form for microscopic examination using transmitted light. With the use of the light microscope projection apparatus, the areas cleared by acetone were then projected at 1,000X and counted. As in the case of the cascade impactor samples, fibers were also noted on the molecular filters; however, in no case was the fiber concentration great enough to hinder analysis.

Microphotographs of the five stages of a representative cascade impactor and a molecular filter are shown in Figure 3.1. The molecular filter and the first and second impactor stages were magnified 280X, the third and fourth stages 2,800X, and the fifth 7,500X. Asbestos fibers are seen in stages 2, 3, 4, and 5. The foggy background on the 5th stage is due to oil deposits. The porelike background on the molecular filter microphotograph is characteristic of the filter after the addition of acetone.

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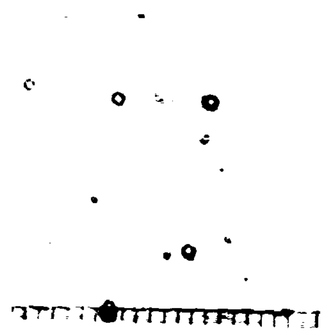


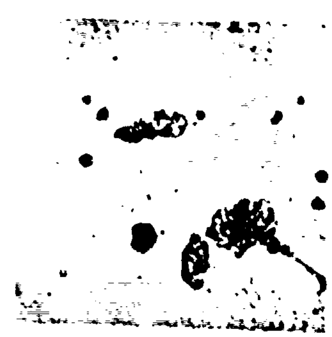
1st Stage

2nd Stage

3rd Stage

4th Stage

5th Stage



Molecular Filter

Fig. 3.1 Shot 4, Station 7-204, Ground Level Cascade Impactor and Molecular Filter Photomicrographs

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CHAPTER 4

RESULTS

4.1 PARTICLE SIZE AND NUMBER DISTRIBUTION

4.1.1 Cascade Impactors

The cascade impactor samples were analyzed for particle size data only. Figure A.1 is a sample calculation sheet for a complete cascade impactor sample. The number of particles in each class interval on each jet, corrected by the jet area factor, has been entered in the appropriate position in the first five columns. The total number of particles in each class interval was then obtained by adding the entries in each row. The remainder of the sheet consists of the calculations leading to cumulative per cent undersize by number, by surface, and by mass. The average diameter, Dav, was calculated from the size and the total number columns. Previous to the analysis of the complete impactor sample, each individual jet was analyzed in the manner just described. The number, median diameter, surface median diameter, mass median diameter, geometric standard deviation, average diameter, total number, summation of median diameter squared, and summation of median diameter cubed for each jet and each impactor are shown in Figures A.2 and A.3. Log-probability plots were made for each complete impactor sample. These plots are shown in Figures A.4 through A.16. Plots of particle size distribution for each impactor, on log-linear paper, are shown in Figures A.17 through A.29. The mean size of each range, where a range of one half to twice the stated size was used, has been plotted against the average number/cc of air in the range. Table 4.1 lists the particle concentration of each impactor; how this concentration was determined is shown in Table A.1.

In general, calculations were carried out to four significant figures and the final values were then reduced to three significant figures. The use of two significant figures would be more in keeping with the accuracies expected. The impaction area measurements have a possible error of $\pm$ 10% due to their imperfect definition; and, the possible error arising from misclassifying a particle by one class interval is also about $\pm$ 10%. Since a large number of particles (approximately 500/jet or 2,500 impactions) were measured, it is probable that values based on calculations (average diameter, total number, etc.) are accurate to $\pm$ 10%. The median diameters and the geometric standard deviation for each sample were obtained from lines drawn to represent the trend of the data.

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4.1.2 Molecular Filters

The number of particles with diameters of one micron or more per square centimeter of molecular filter was determined and the number of such particles per cubic centimeter of air calculated. The results are shown in Table 4.1. Particles below one micron in diameter were not counted because this size is near the limit of resolution of the light microscope and therefore difficult to examine. Figures A.30 through A.49 are graphs showing the number of particles per cubic centimeter of air as a function of particle size.

4.1.3 Correlation of Cascade Impactor and Molecular Filter Data

Dust concentration on filter samplers and cascade impactors are in fair agreement. For example, at Station F-204-U, 6.2 per cent of the impactor particles were greater than one micron in diameter. From Table 4.1, 7.65×10^4 particles/cc of air greater than one micron were counted on the filter, giving $7.65 \times 10^4 \div 0.062 = 1.2 \times 10^6$ particles/cc of air on the filter. The impactor results from this station are 1.72×10^5 particles/cc of air.

4.1.4 External Factors Affecting Results

Throughout the operation, cascade impactor samples were more easily spoiled by foreign material than were the molecular filter samples.

Cascade impactor samples for Shot 1 at the ground level of both stations were rendered useless by an oily mist. It was suspected that this oil was from the cables supporting the 50-ft. towers. During succeeding shots, these cables were wrapped with aluminum foil to prevent vaporization of oil. However, both of the impactors at station 7-201 collected oil during Shot 2.

Carbon particles, mixed with the sample obtained during Shot 3 by the station 7-202 impactor at ground level, made analysis impossible. The carbon probably came from burning sagebrush fragments.

The shock wave of Shot 4 destroyed the impactor samples at station 7-202 and station 7-204 and also the filter samplers at the 10 ft. level. The filter sampler at the station 7-202 ground level collected a large amount of dust.

Fibers were found on several cascade impactor slides, thereby making analysis of the slides difficult. These fibers were found to be crocidolite asbestos fibers which are a component of the filter material used in the Chemical Corps Aerosol Canister, E-12.

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TABLE 4.1

Cascade Impactor and Molecular Filter Concentration Data

Station	Particles Per cc (by impactor)	Particles Per cc (by filter)	Percentage of Particles Over 1 Micron (by impactor)	Total Particles on Filter	Condition of MF When Removed From Holder
F-202U	1.06×10^6	3.52×10^4	10.5	3.4×10^5	
F-202L	oil deposit	4.19×10^4			Traces of loose dust
F-204U	1.72×10^5	7.65×10^4	6.2	1.2×10^6	
F-204L	oil deposit	2.44×10^4			Grayish
B-201U	oil deposit	1.05×10^4			
B-201L	oil deposit	3.15×10^4			
B-202U	1.41×10^5	1.02×10^4	3.3	3.1×10^5	Traces of loose dust
B-202L	3.57×10^5	9.74×10^3	3.5	2.1×10^5	
B-204U	2.86×10^4	2.97×10^3	5.3	5.6×10^4	
B-204L	2.95×10^4	2.60×10^3	3.8	6.8×10^4	
C-201U	2.53×10^3*	2.12×10^2*	3.4	6.2×10^3*	
C-201L	1.65×10^3*	2.10×10^2*	2.0	1.1×10^4*	
C-202U	4.10×10^4	1.02×10^4	5.0	2.0×10^5	Traces of loose sand
C-202L	carbon deposits	1.10×10^5			Traces of loose sand
C-204U	9.34×10^4	2.77×10^3	1.1	2.5×10^5	
C-204L	9.07×10^4	5.22×10^4	7.2	7.2×10^5	Traces of loose sand
D-201U	Smashed	Blast			Burned
D-201L	Full of Dirt	Blast			Burned
D-202U	Smashed	Blast			Broken
D-202L	Damaged	8.31×10^6			Scorched
D-204U	1.19×10^5	3.91×10^3	2.4	1.6×10^5	
D-204L	2.22×10^5	2.49×10^4	4.0	6.2×10^5	Loose sand
D-204BG	Not used	1.20×10^3*	4.0	3.0×10^4	

U refers to 10 ft. level stations
L refers to ground level stations
BG or * refers to background
F, B, C, and D refer to Shots 1 (Frenchman Flat), 2,3,and 4, respectively.

[redacted]

[redacted]

4.2 Ranges to Stations

The nominal, ground and slant ranges to each station are shown in Table 4.2.

TABLE 4.2

Ranges to Stations

Station	Nominal Ground Range Ft	Actual Ground Range Ft	Actual Slant Range Ft
F-202J	500	580	980
F-202L	500	580	980
F-204U	1000	1070	1330
F-204L	1000	1070	1340
B-201U	750	630	1270
B-201L	750	630	1270
B-202U	1500	1380	1770
B-202L	1500	1380	1770
B-204U	3000	2890	3100
B-204L	3000	2890	3100
C-201U	750	660	3500
C-201L	750	660	3500
C-202U	1500	1400	3710
C-202L	1500	1400	3720
C-204U	3000	2900	4500
C-204L	3000	2900	4510
D-201U	750	680	1240
D-201L	750	680	1250
D-202U	1500	1390	1730
D-202L	1500	1390	1740
D-204U	3000	2870	3050
D-204L	3000	2870	3050
D-204BG	3000	2870	3050

U refers to 10 ft. level stations
L refers to ground level stations
BG or * refers to background
F, B, C, and D refer to Shots 1 (Frenchman Flat), 2, 3, and 4, respectively.

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CHAPTER 5

DISCUSSION

5.1 MECHANISM OF SAMPLING

The technique of sampling the pre-shock dust using sampling periods of the order of one second was entirely successful. All sampling stations operated as planned.

5.2 DIFFERENCE IN RESULTS

The number of particles per cubic centimeter of air as determined by the impactor analysis was usually one-half to one-third of the estimated number of particles on the corresponding filter sampler. The disparity in the results may be due to non-isokinetic sampling, the effect of which cannot be estimated.

5.3 RESULTS

The data show the order of magnitude of the pre-shock dust concentration at ground and 10 feet levels and also background or normal dust concentrations. No information was obtained on the particle concentration at heights greater than 10 ft. above the ground; consequently no estimate could be made of the total number of particles raised by the thermal wave.

Table 4.1 shows that the pre-shock dust concentrations are generally ten to several hundred times the background or normal dust concentrations. As an example, for Shot 3, the pre-shock dust concentrations as determined from filter samples range from a minimum of 2.77×10^3 to a maximum of 1.1×10^5 particles/cc while the background concentrations are 2.1 x 102. The ratios of pre-shock to background dust concentrations for these stations range from approximately 10 to 500.

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CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The presence of pre-shock dust with concentrations of from ten to several hundred times background or normal dust concentration has been established. The depth of the dust layer extends to at least 10 ft. above the ground surface. Dust concentrations decreased slightly between stations 7-202 and 7-204 at both sampling levels. Little variation of dust concentrations from shot to shot was shown.

Although the soil moisture content was usually abnormally high, dust concentrations several hundred times background were obtained. This was particularly true for Shot 4. The ground was thoroughly soaked from rainfall and a heavy dew, and yet, as much dust was produced at station 7-204 as on Shot 3. However, the thermal radiation was higher on Shot 4 than on any other shot.

There was no significant difference between the particle size distribution of pre-shock dust and background dust. The pre-shock dust particles appeared to be similar to the background particles although on some samples from Shots 3 and 4 there appeared to be traces of transparent, spherical particles. These were probably particles of fused sand.

6.2 RECOMMENDATIONS

If analysis of the blast phenomena indicates a need for the data, improved techniques should be developed to sample pre-shock dust on future atomic weapons tests. In order to determine the depth of the dust layer, samples should be collected at several heights ranging from zero to considerably more than 10 ft. above the ground.

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APPENDIX A

PARTICLE DISTRIBUTION DATA

TABLE A.1

Particle Concentration From Cascade Impactors

Station	Sampling Time (Sec) ***	Flow Rate cc/sec	Sample Volume cc*	Total Particles On Impactor	Particles Per cc**
F-202U	0.45	215	19	2.00×10^7	1.06×10^6
F-202L	0.48	223			
F-204U	0.72	208	72	1.24×10^7	1.72×10^5
F-204L	0.72	223			
B-201U	0.34	203			
B-201L	0.32	210			
B-202U	0.64	223	65	9.14×10^6	1.41×10^5
B-202L	0.65	217	63	2.25×10^7	3.57×10^5
B-204U	1.70	227	308	8.80×10^6	2.86×10^4
B-204L	1.71	210	281	8.29×10^6	2.95×10^4
C-201U	12.5	208	2522	6.38×10^6	2.53×10^3
C-201L	12.5	210	2522	4.20×10^6	1.65×10^3
C-202U	1.47	208	228	9.35×10^6	4.10×10^4
C-202L	1.46	215			
C-204U	2.05	218	369	2.45×10^7	9.34×10^4
C-204L	2.04	202	334	3.09×10^7	9.07×10^4
D-201U					
D-201L					
D-202U	0.03				
D-202L	0.04				
D-204U	0.89	227	124	1.47×10^7	1.19×10^5
D-204L	0.89	210	109	2.42×10^7	2.22×10^5

* This volume equals the product of flow rate and sampling time minus the 78 cc volume of sample trapped between the inlet and the closed gate valve, which did not reach the impactor. Because of the much larger flow rates through the molecular filters, this 78 cc volume correction was not made for such flow.

** Particle concentration on molecular filters was similarly calculated.

***Detonation to time of blast arrival.

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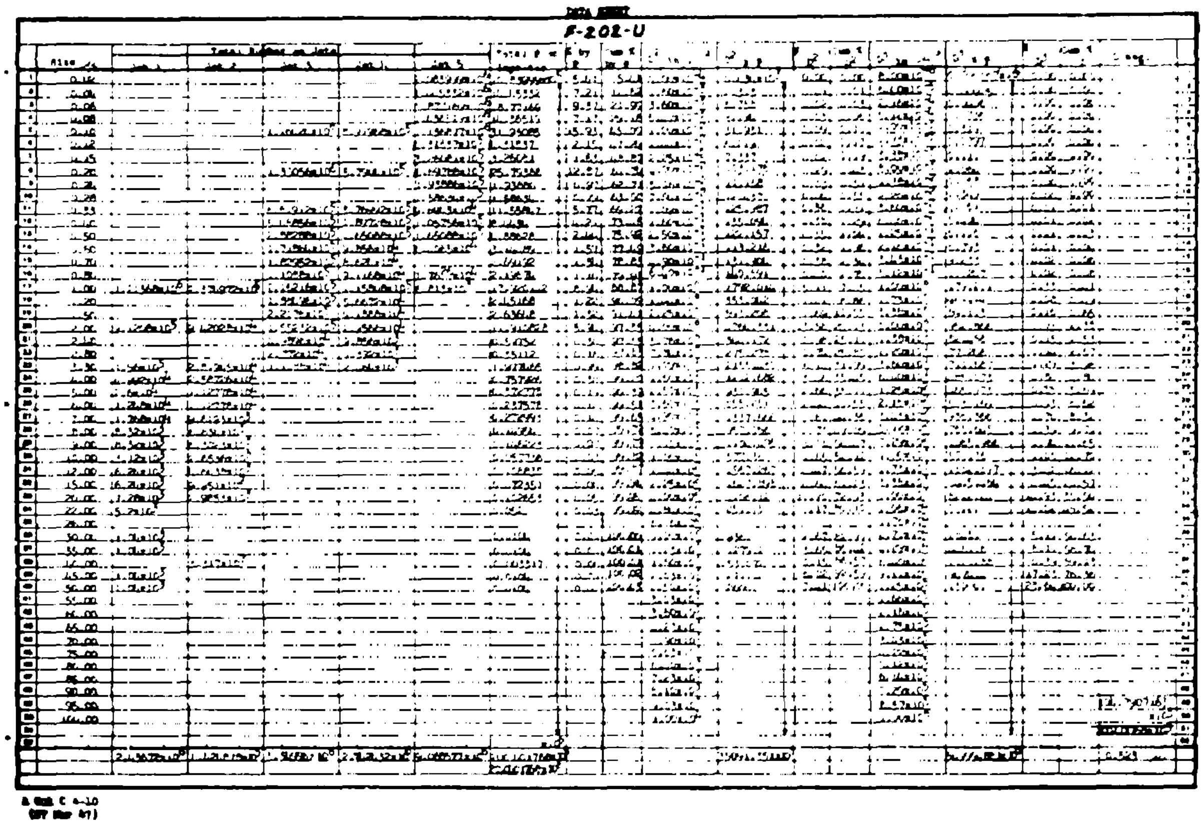

Fig. A.1 Sample Cascade Impactor Calculation Sheet

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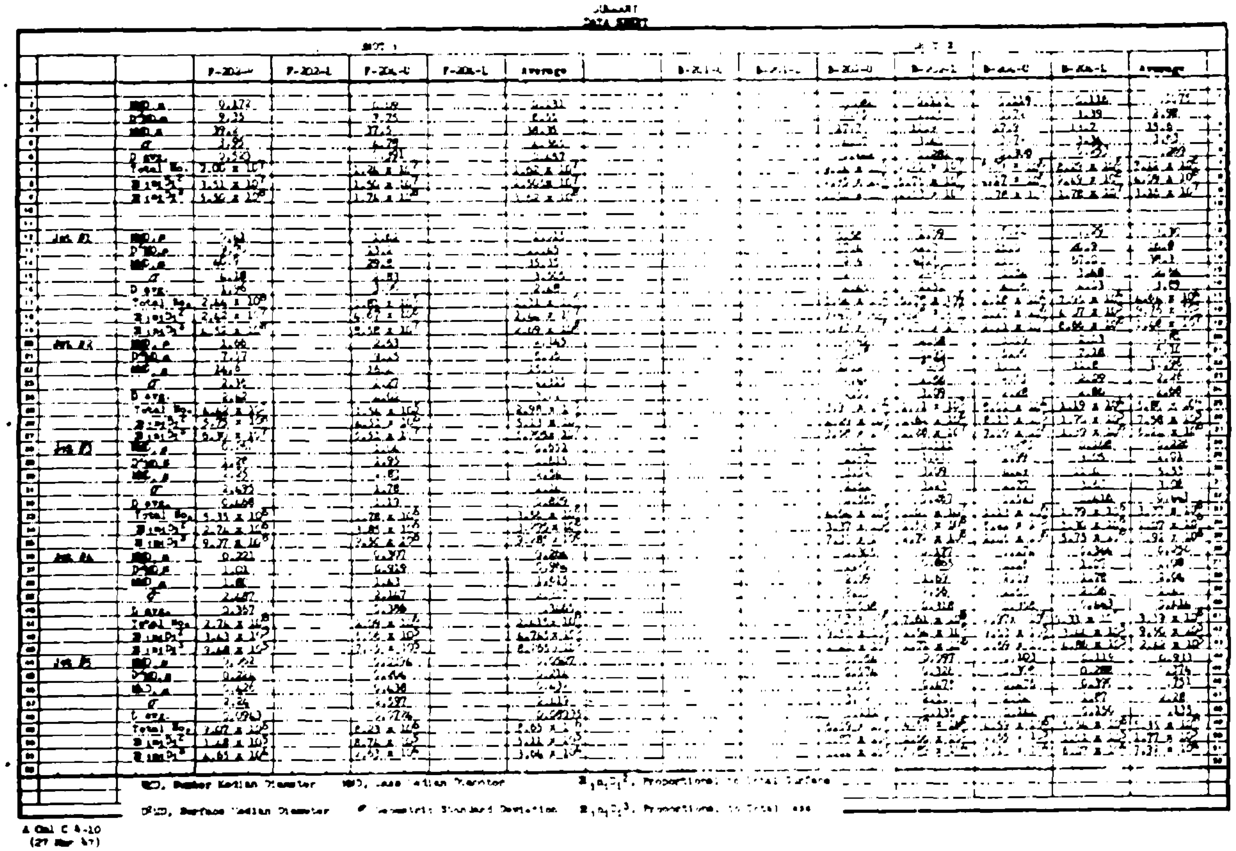

Fig. A.2 Shots 1 and 2, Summary Sheet of Cascade Impactor Data, Individual Jet Sample Parameters

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Fig. A.3 Shots 3 and 4, Summary Sheet of Cascade Impactor Data, Individual Jet Sample Parameters

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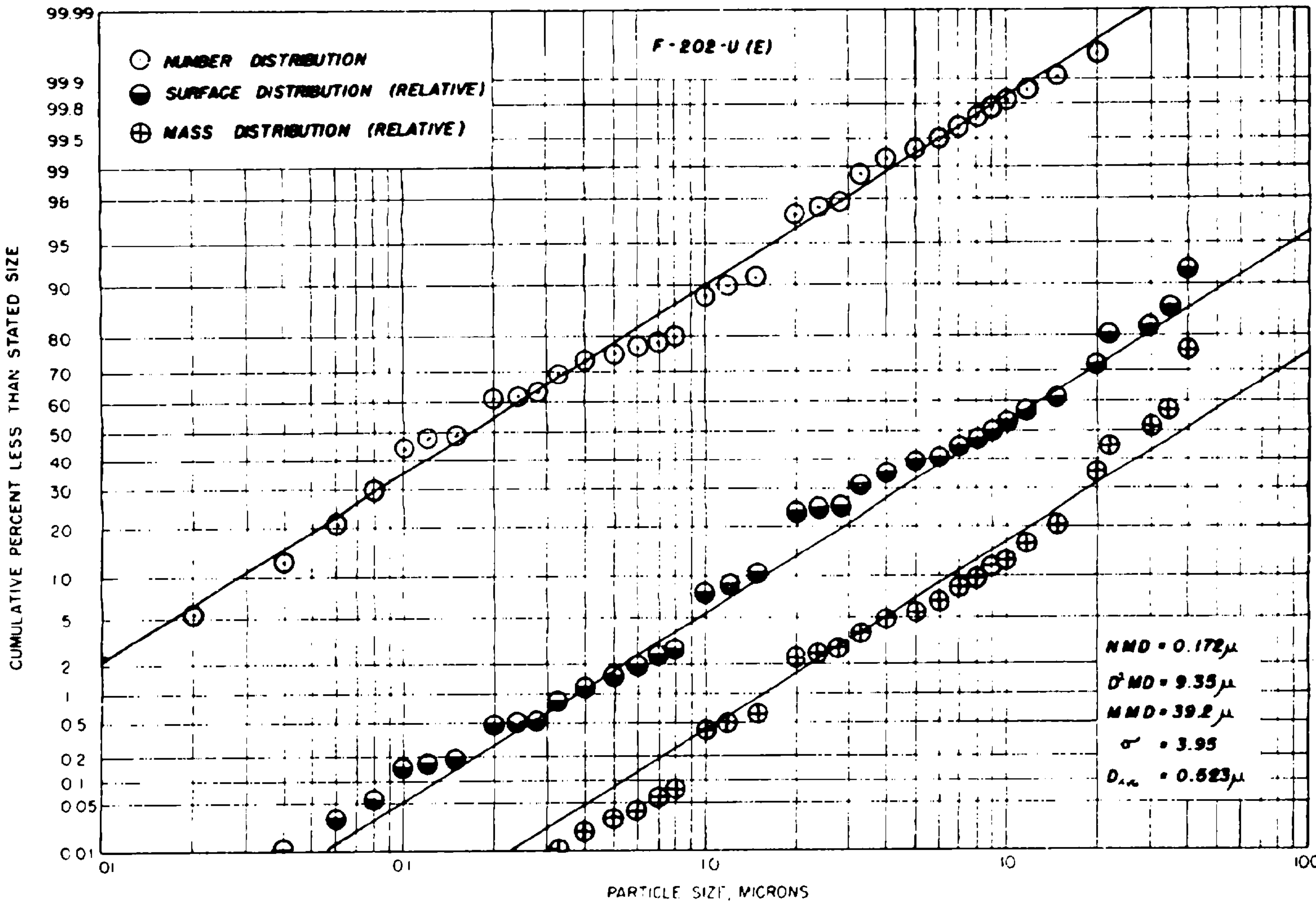

Fig. A.4 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station F-202-J

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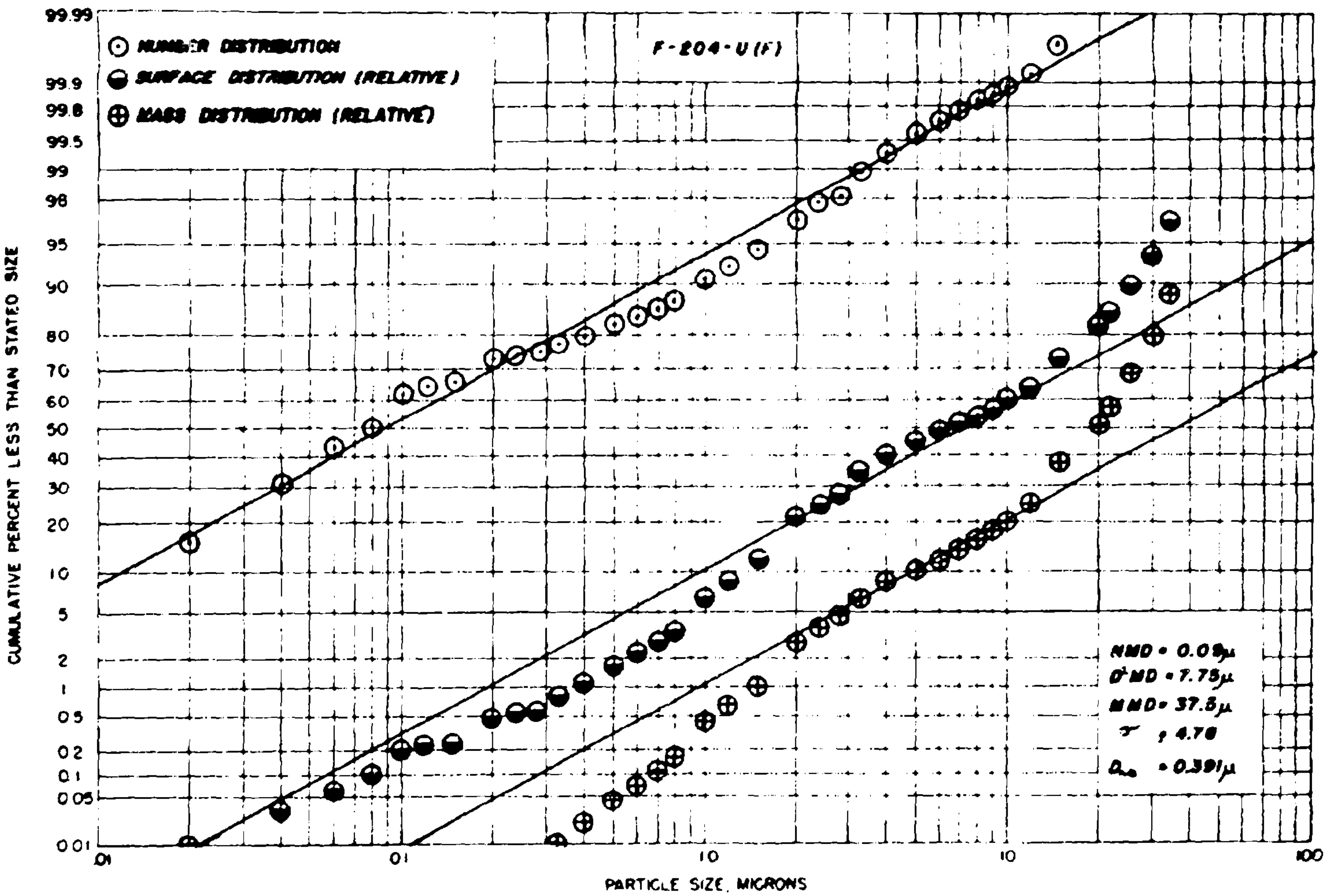

Fig. A.5 Pre-shock Dust Particle Size Distribution, Cascade Impactor Station F-204-J

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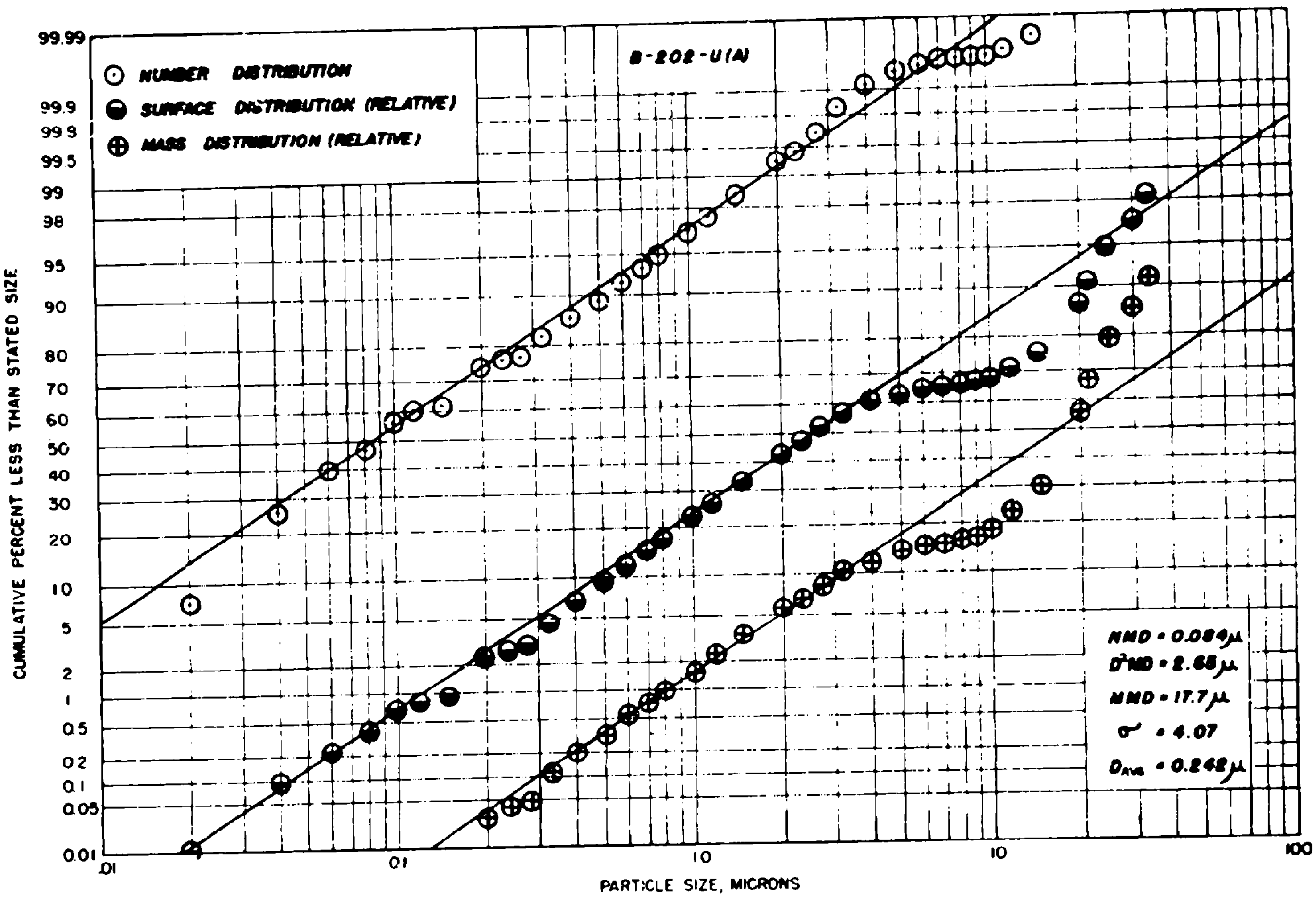

Fig. A.6 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station B-202-U

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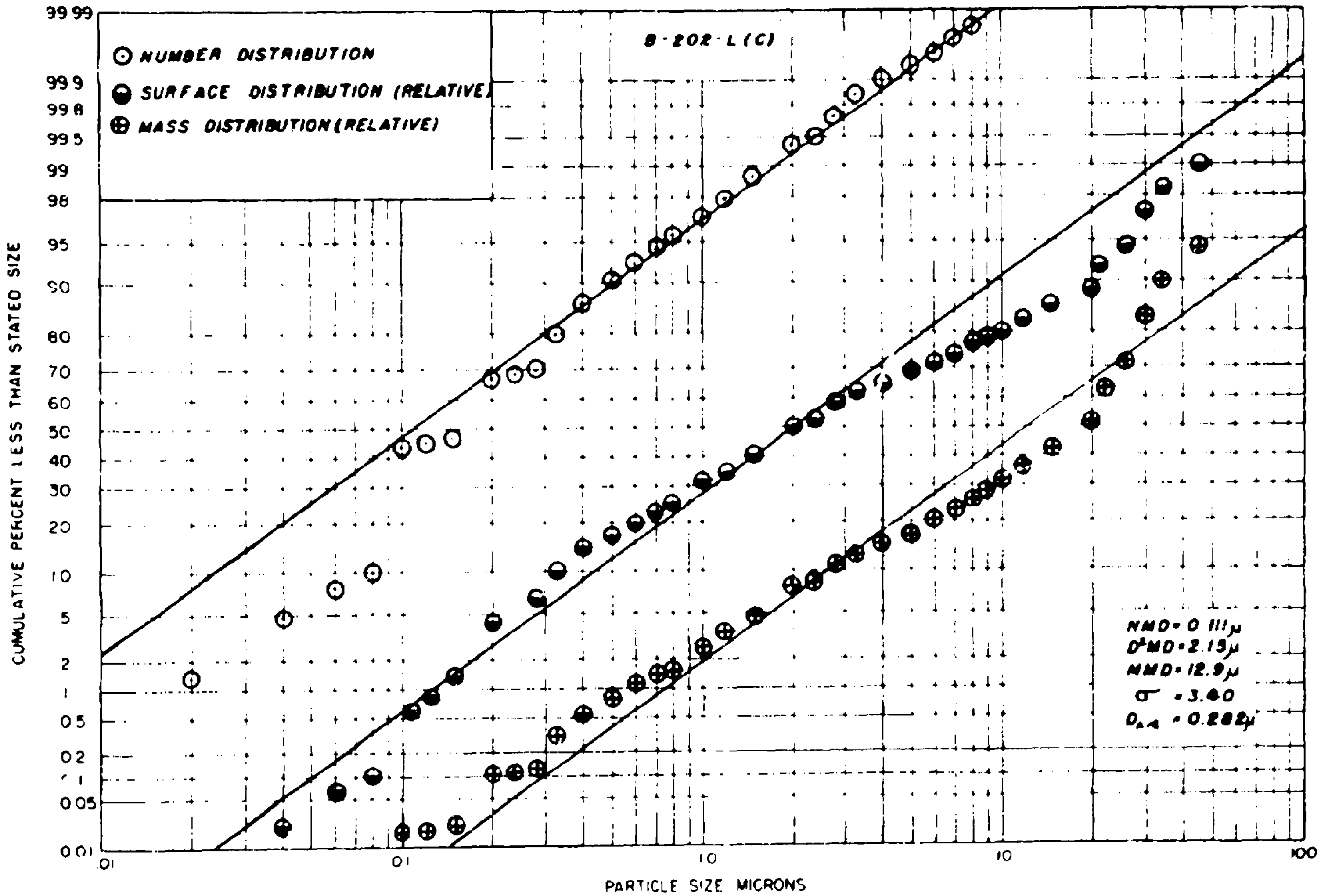

Fig. A.7 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station B-202-L

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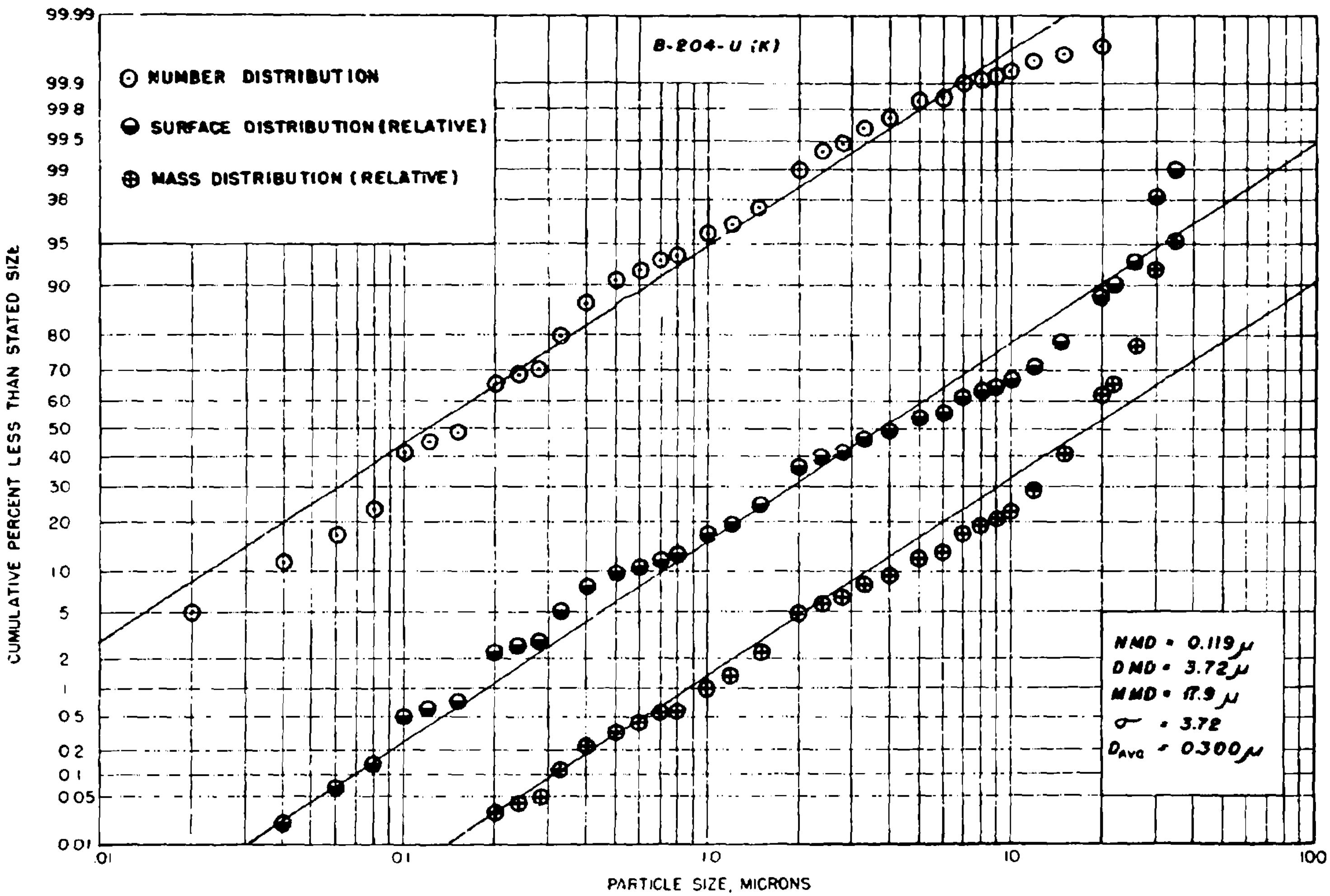

Fig. A.8 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station B-204-U

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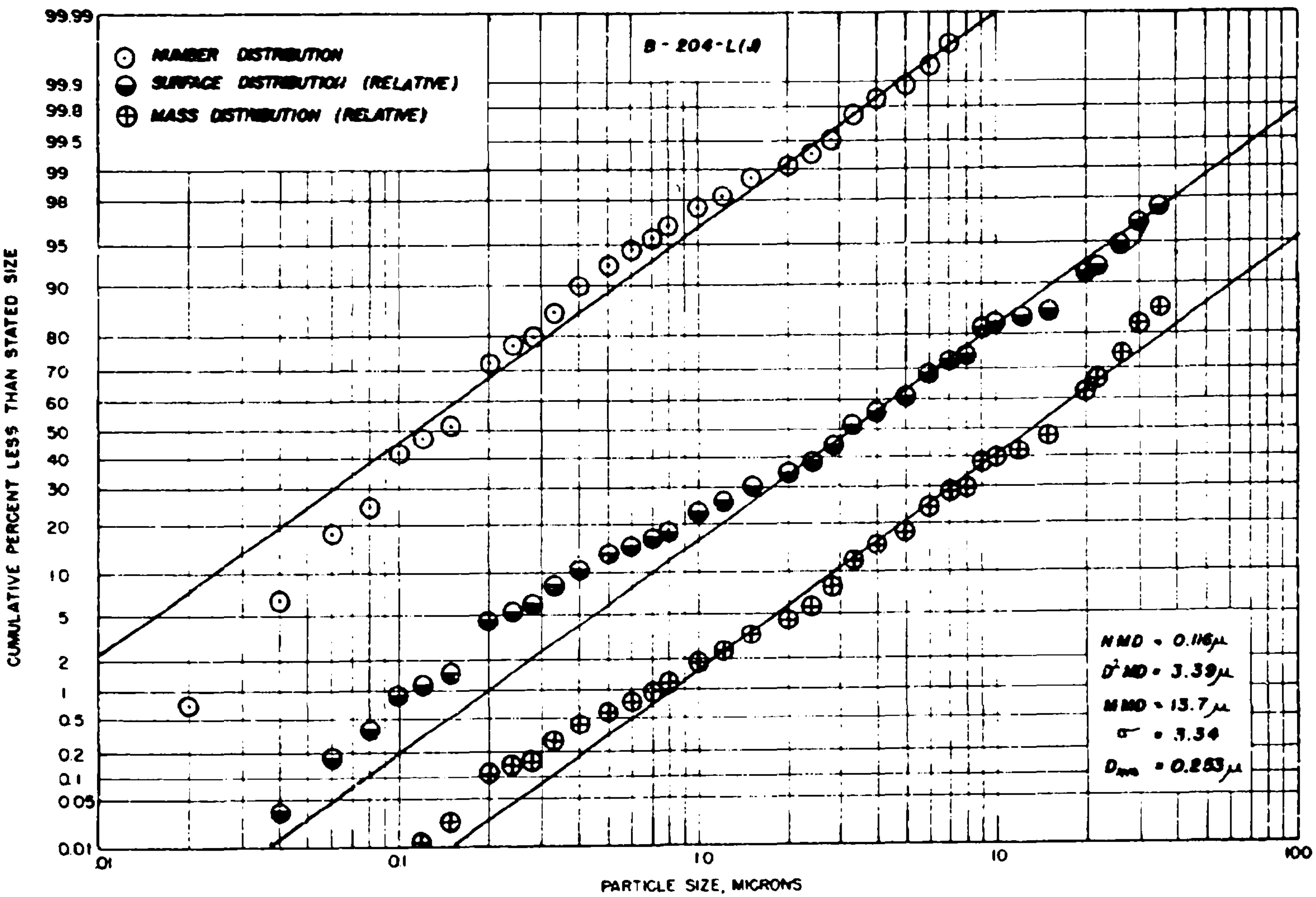

Fig. A.9 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station B-204-L

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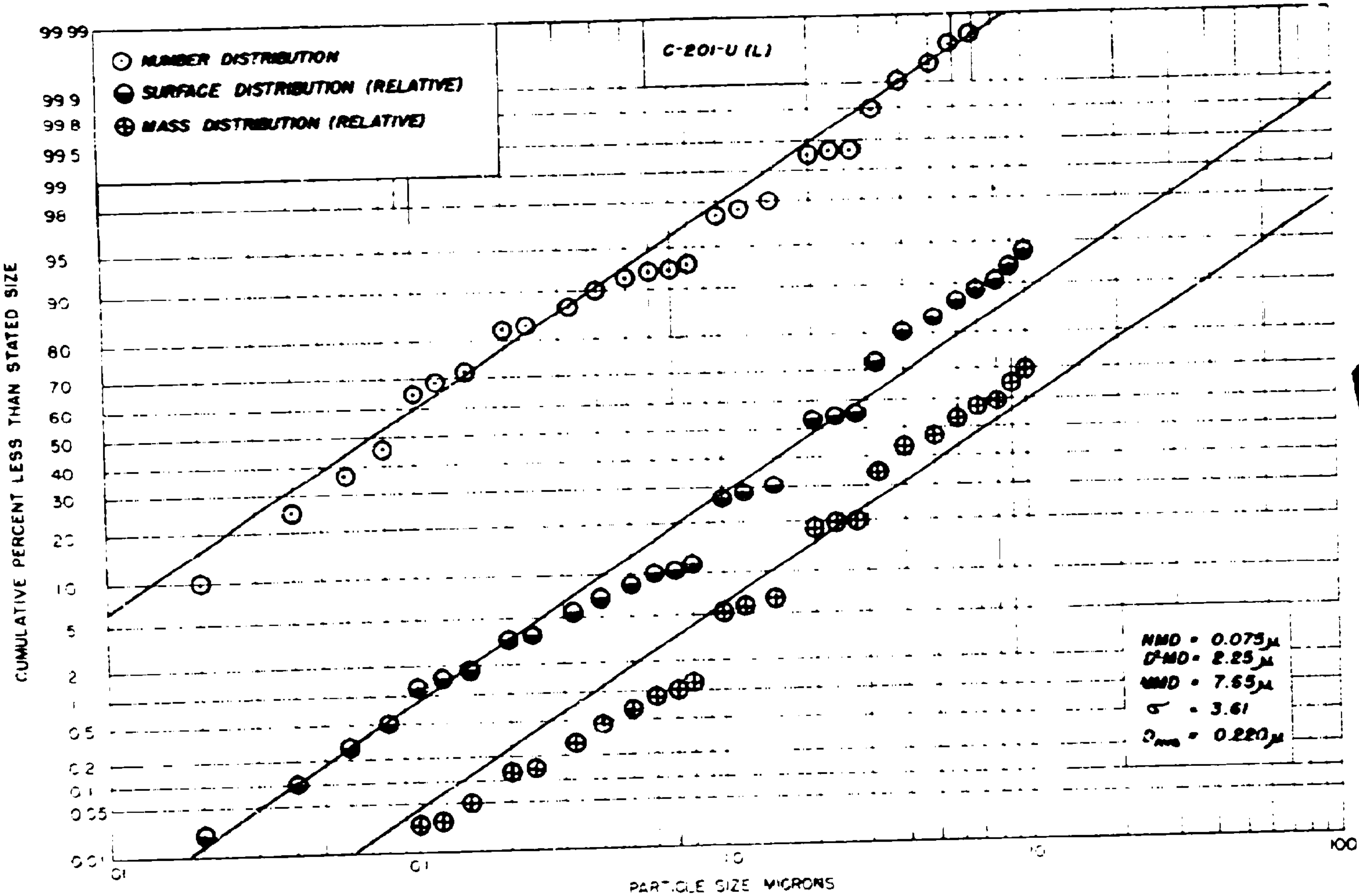

Fig. A.10 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station C-201-U

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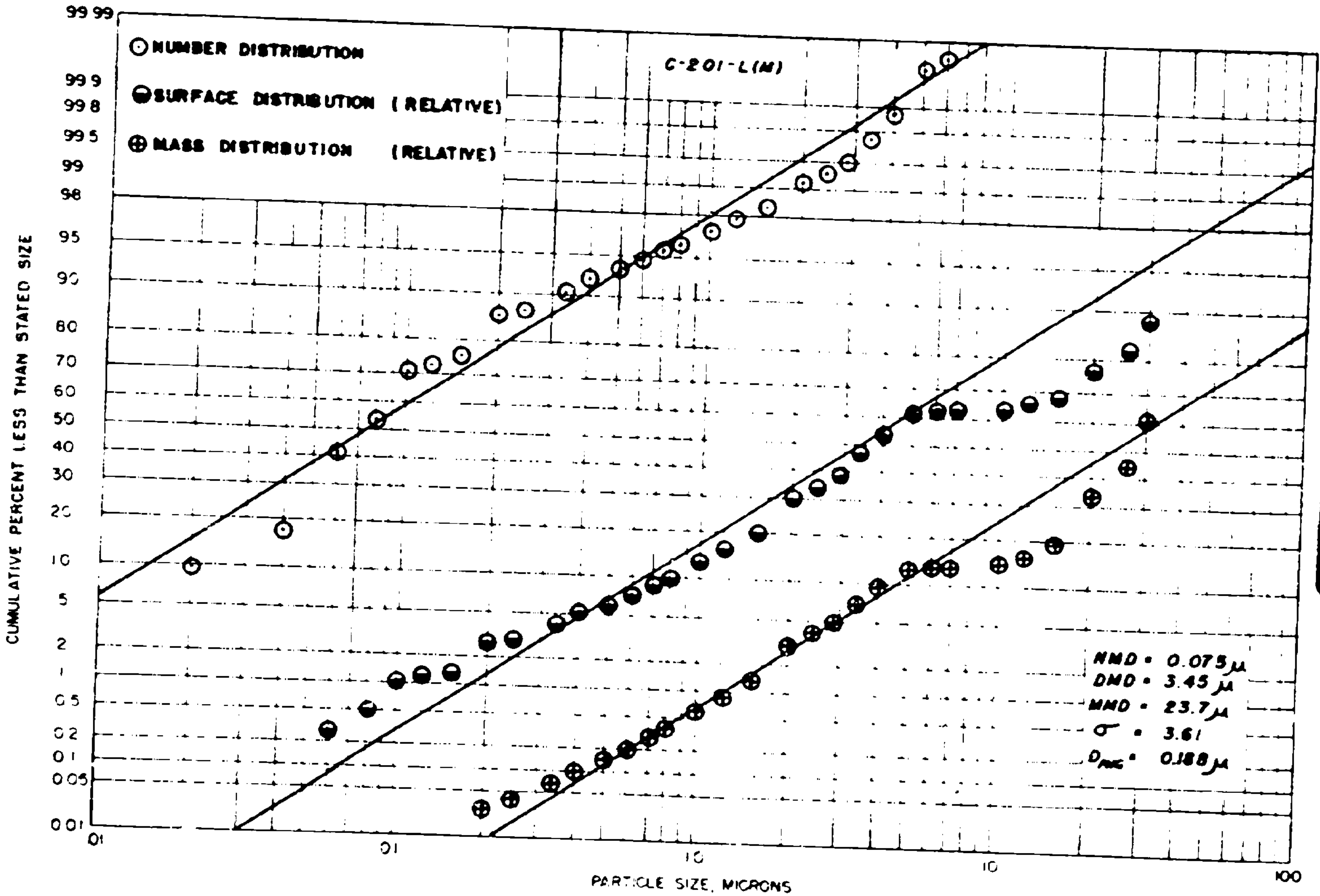

Fig. A.11 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station C-2C1-L

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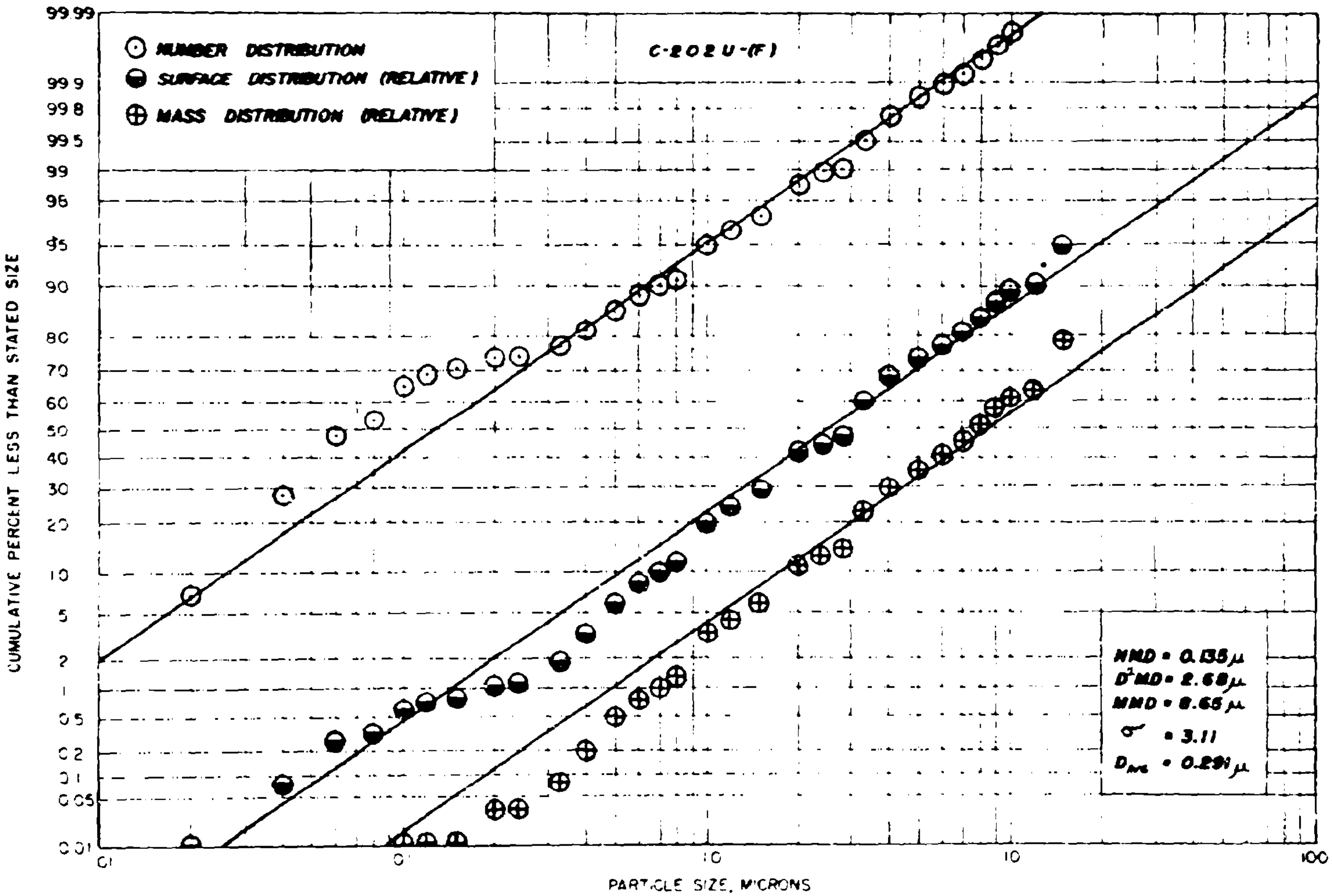

Fig. A.12 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station C-202-U

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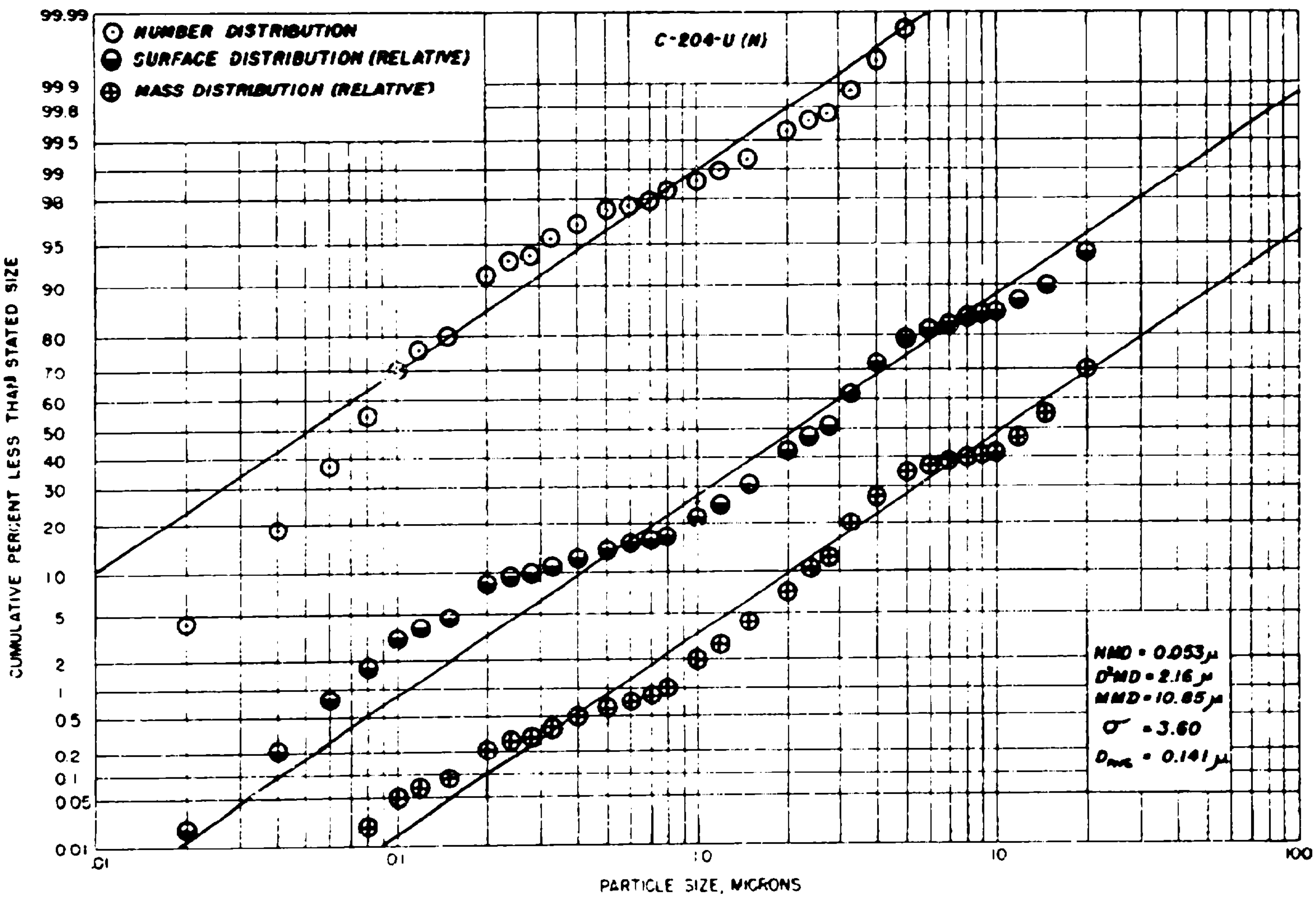

Fig. A.13 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station C-204-U

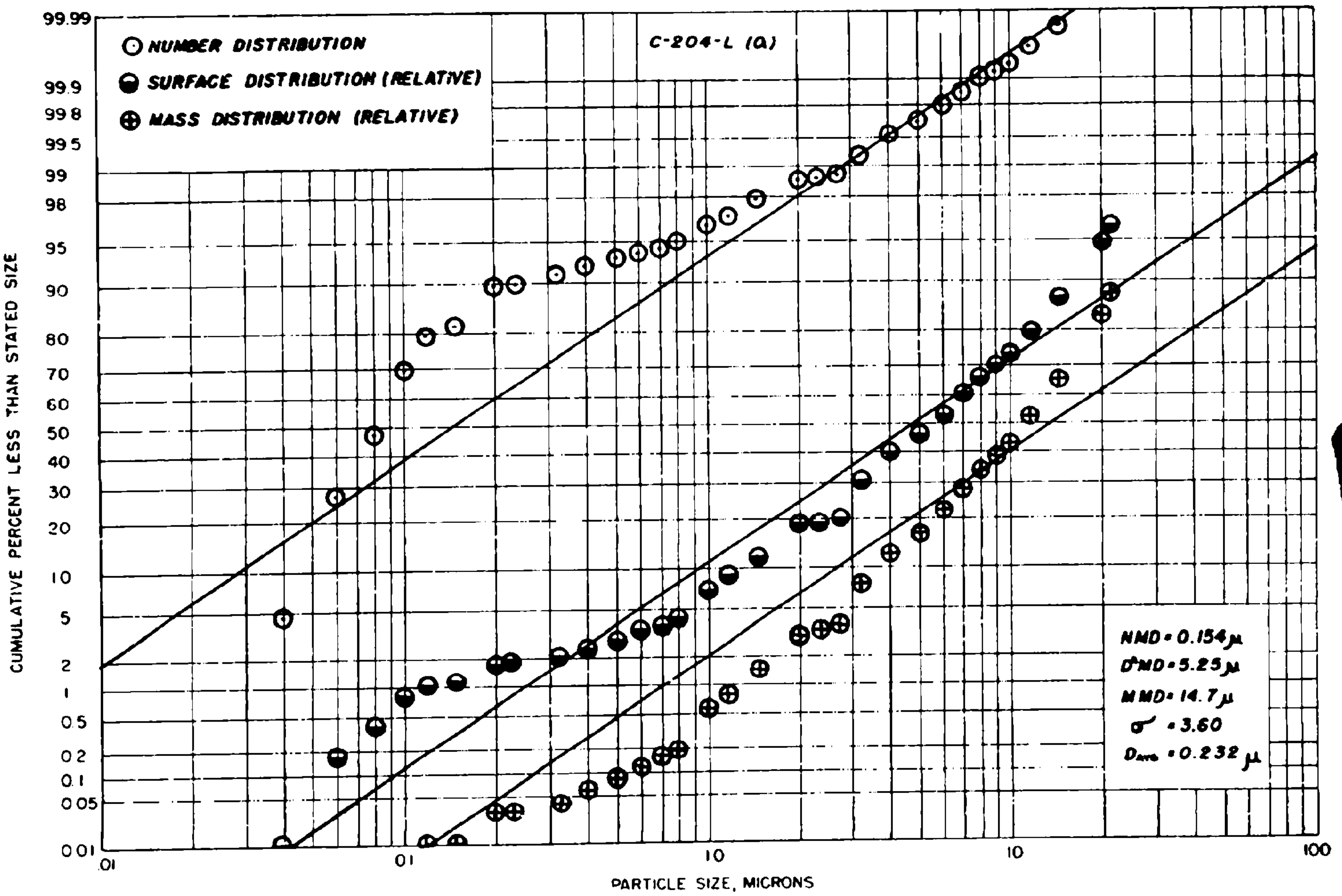

Fig. A.14 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station C-204-L

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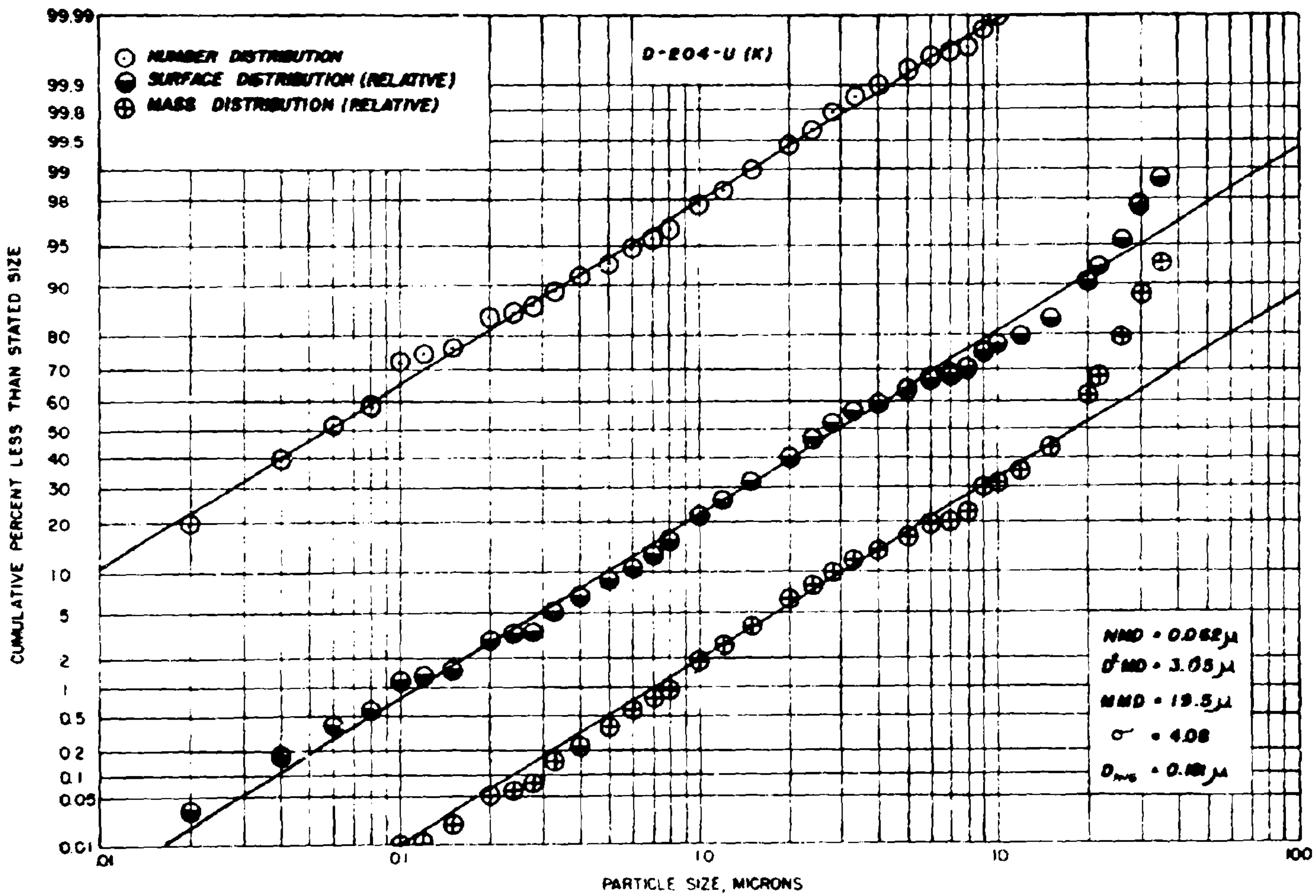

Fig. A.15 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station D-204-U

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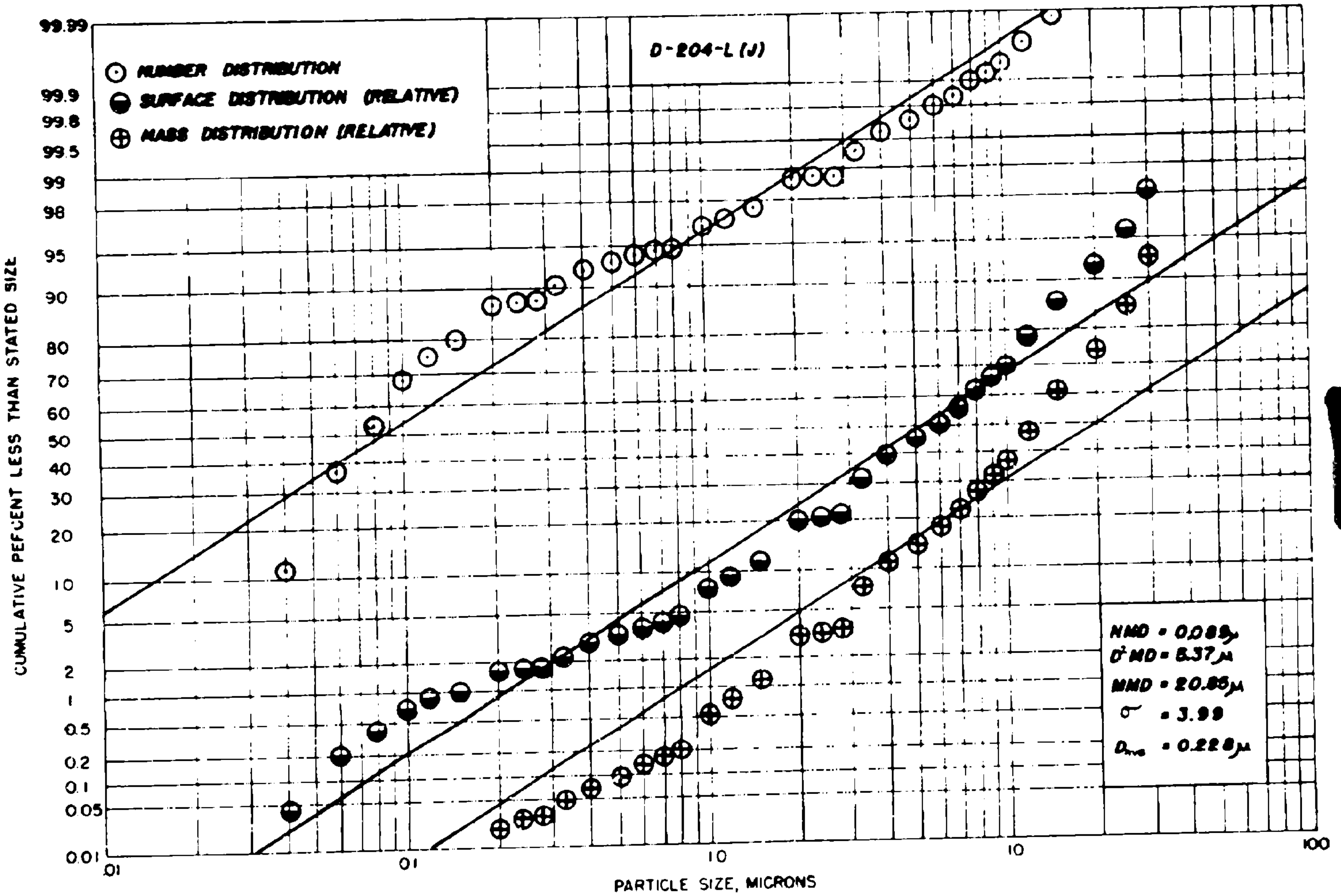

Fig. A.16 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station D-204-L

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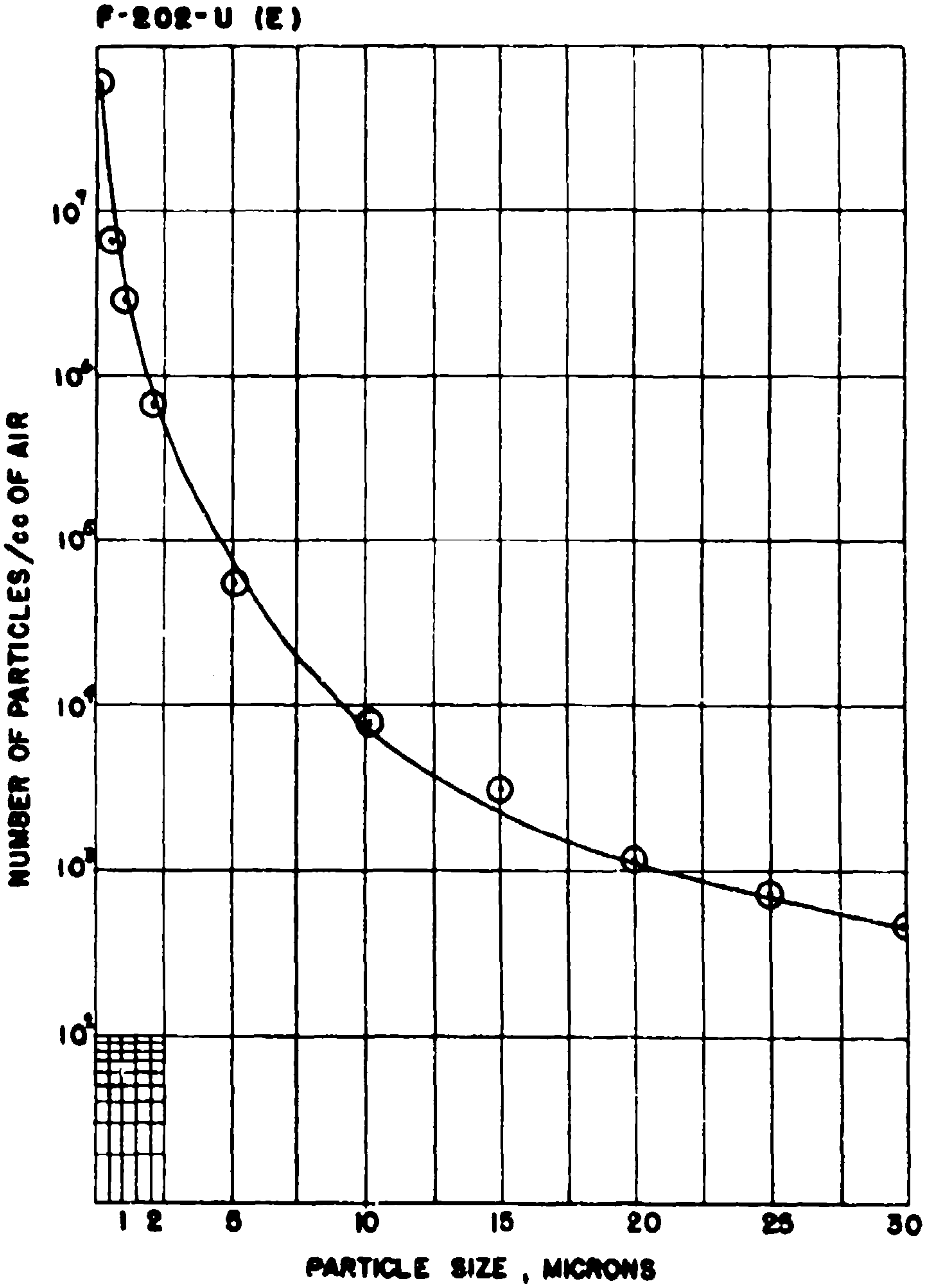

Fig. A.17 Pre-shock Dust Particle Size Distribution
Cascade Impactor, Station F-202-U

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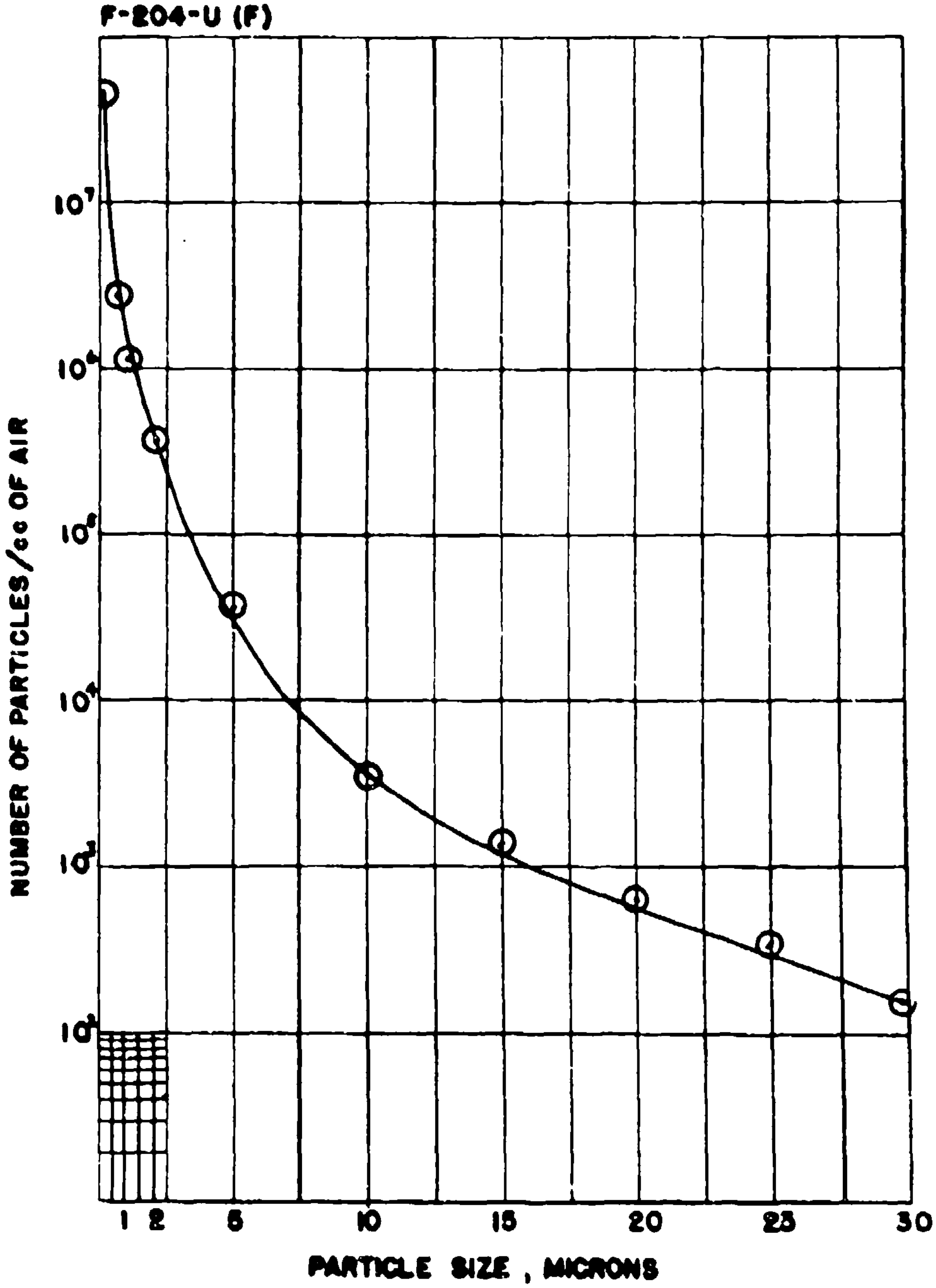

Fig. A.18 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station F-204-U

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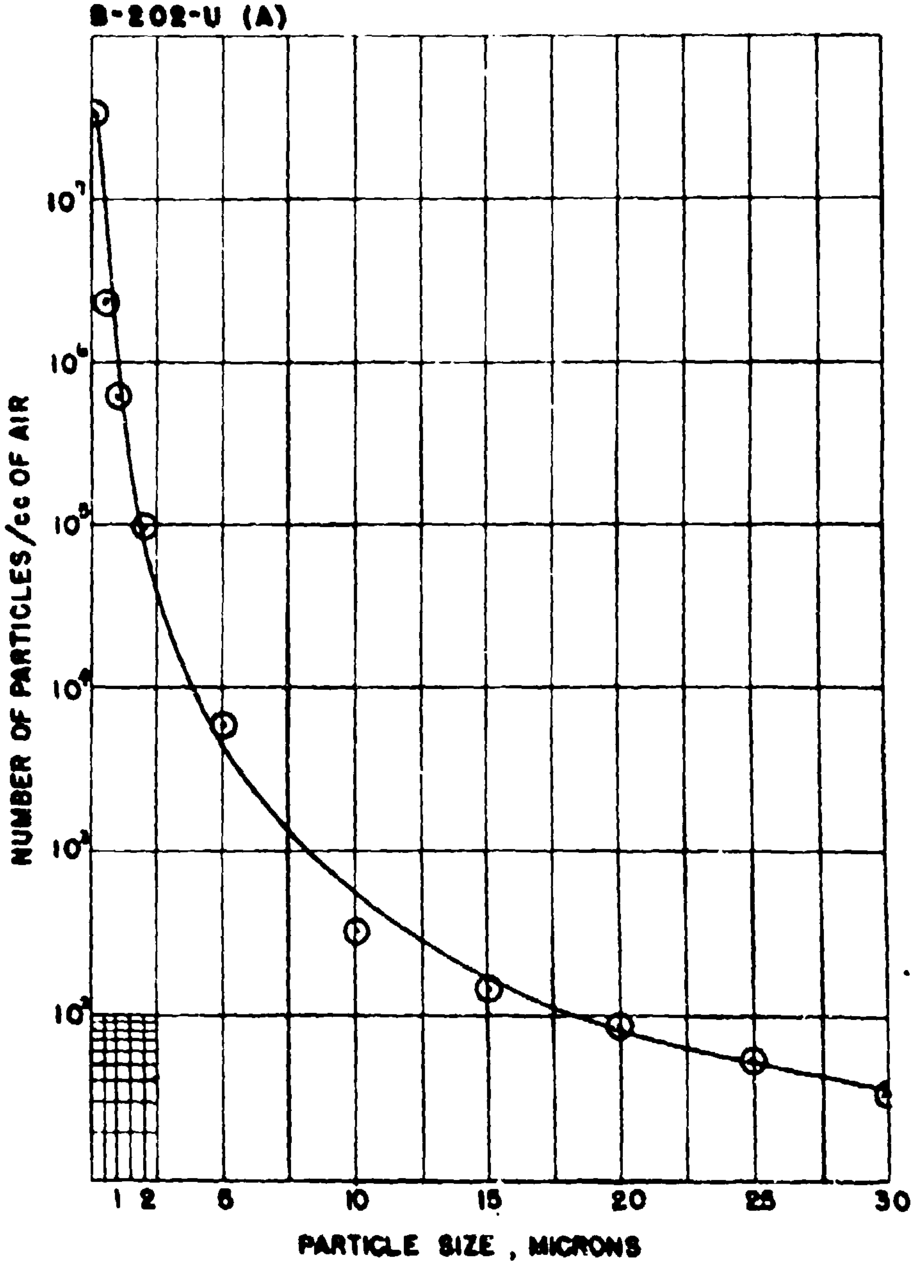

Fig. A.19 Pre-shock Dust Particle Size Distribution,
Cascade Impactor, Station B-202-U

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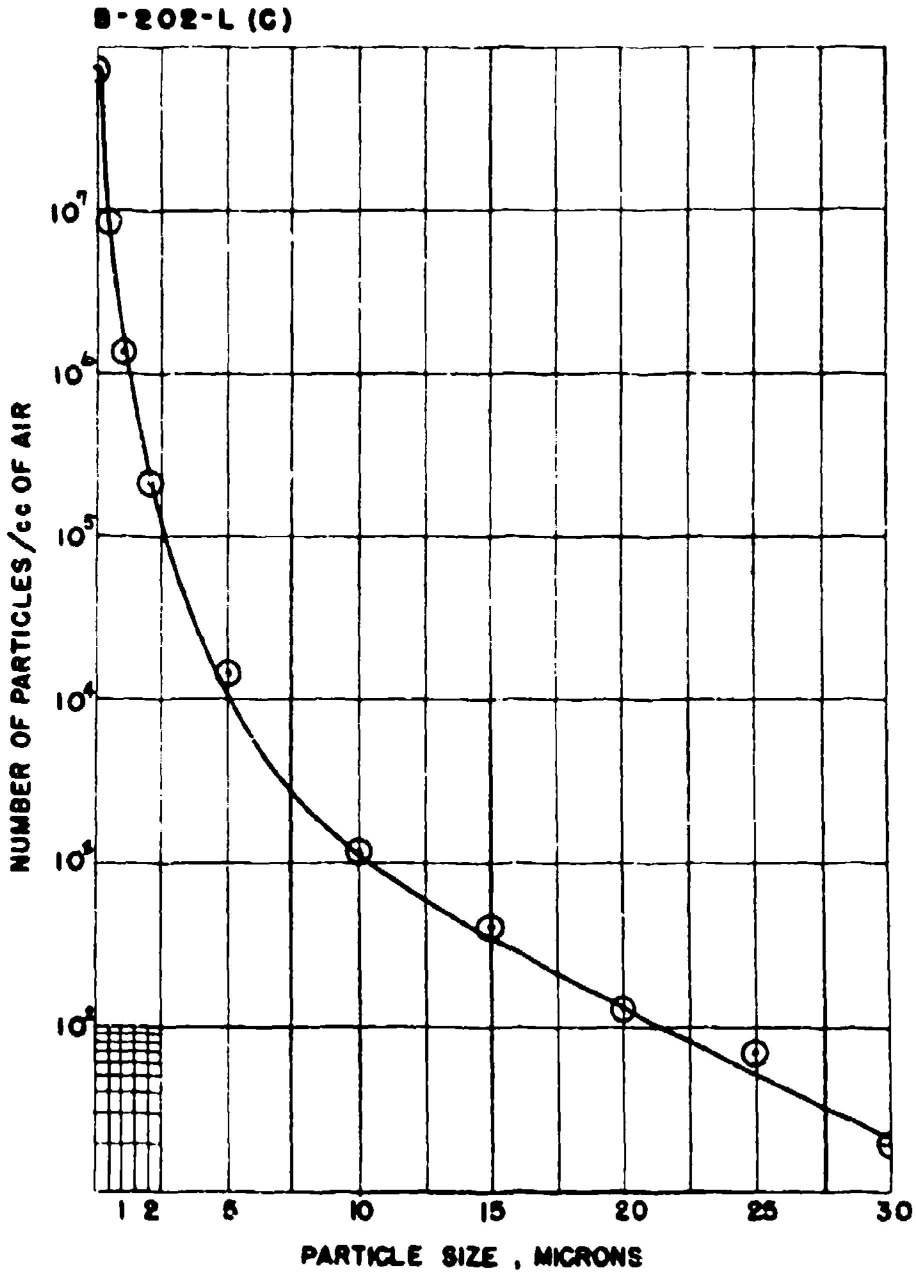

Fig. A.20 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station B-202-L

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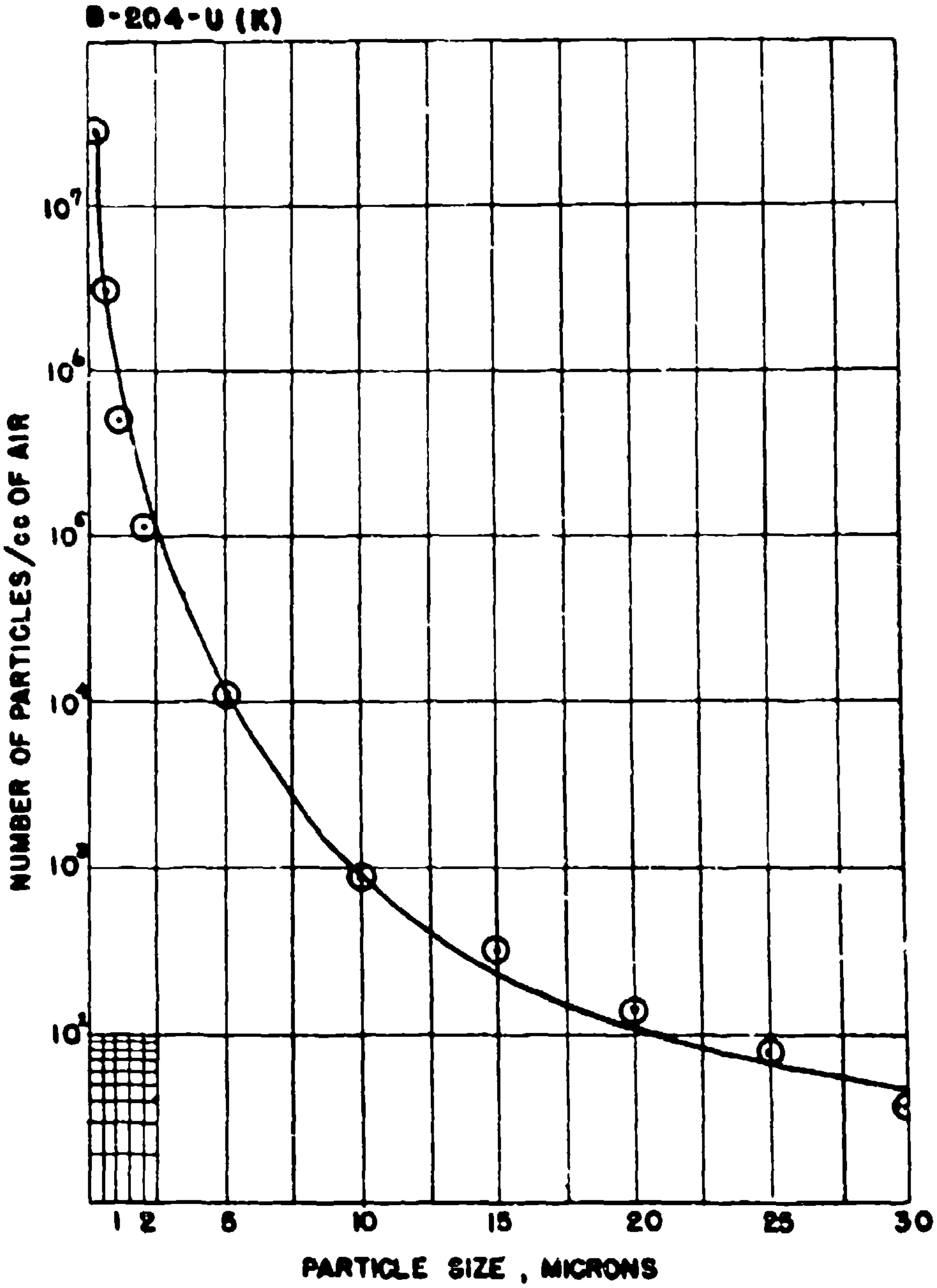

Fig. A.21 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station B-204-U

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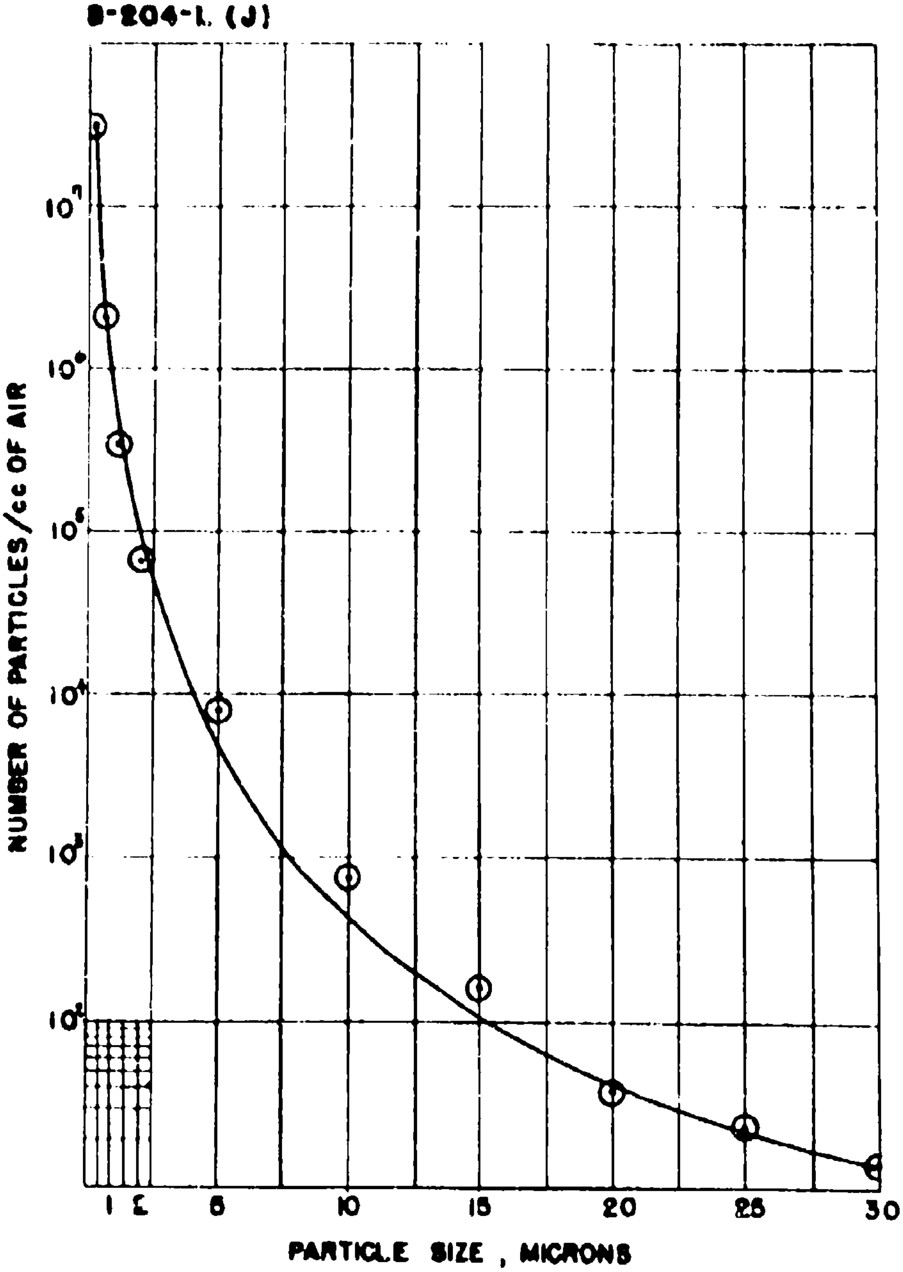

Fig. A.22 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station B-204-L

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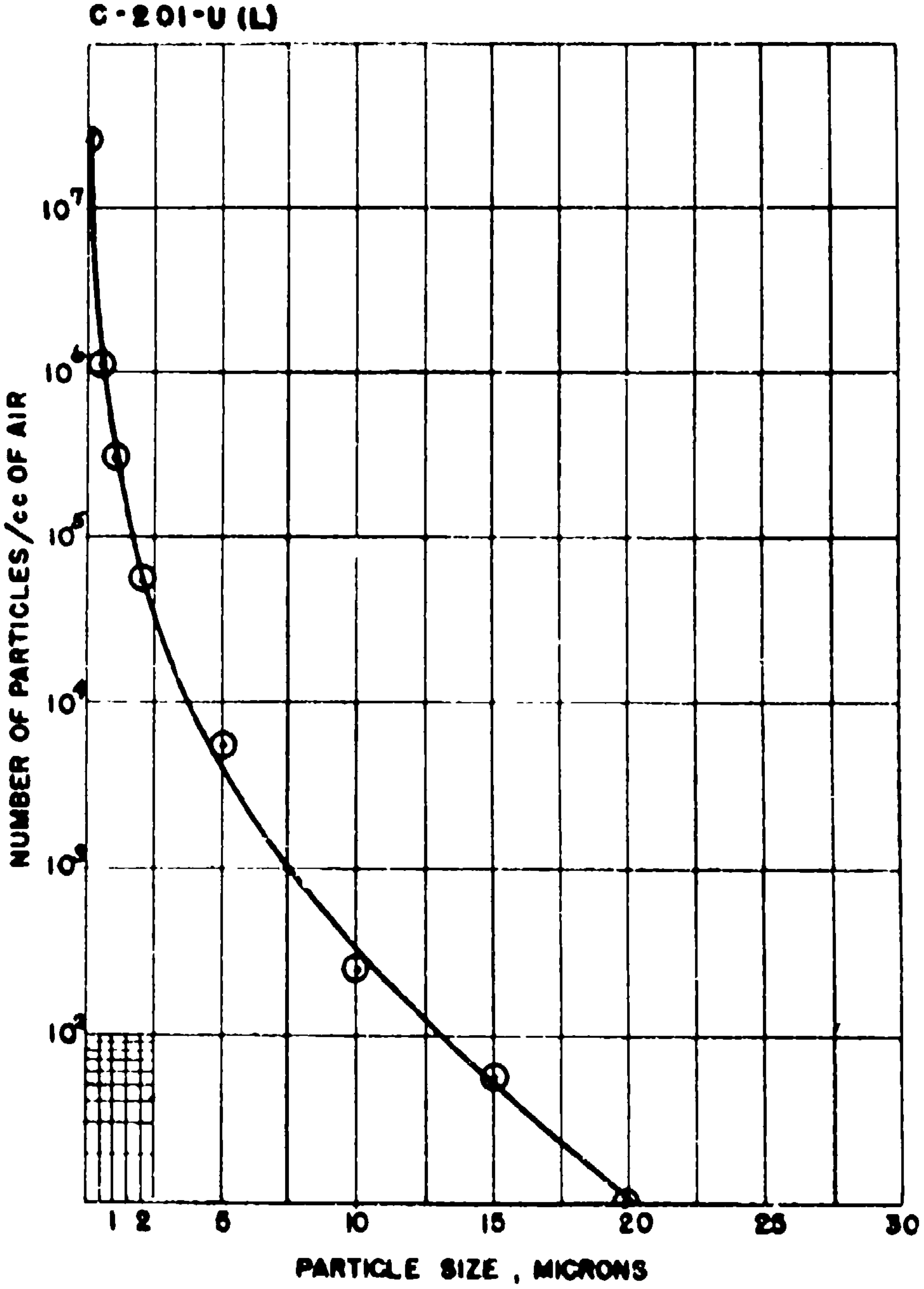

Fig. A.23 Pre-shock Dust Particle Size Distribution
Cascade Impactor, Station C-201-U

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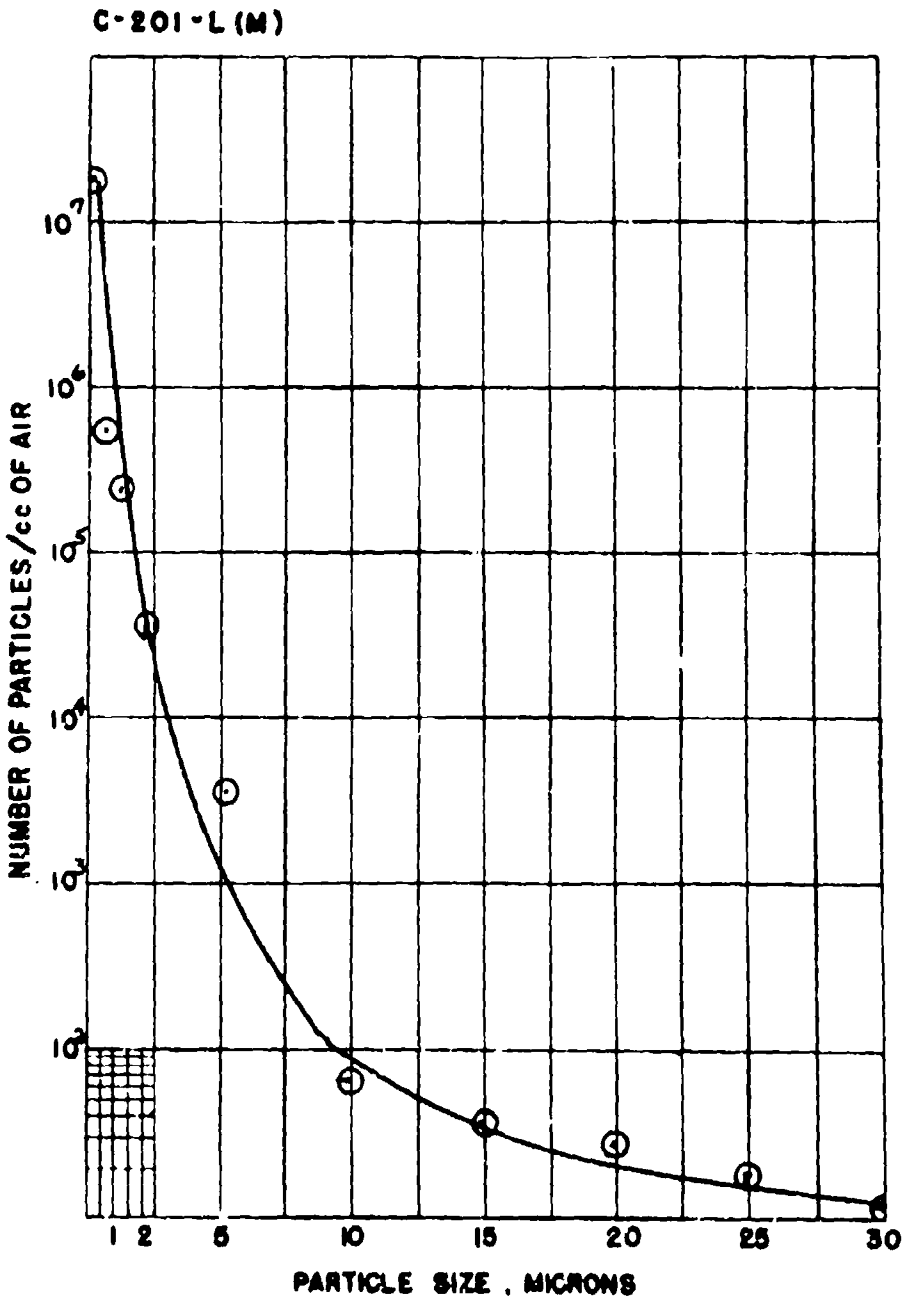

Fig. A.24 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station C-201-L

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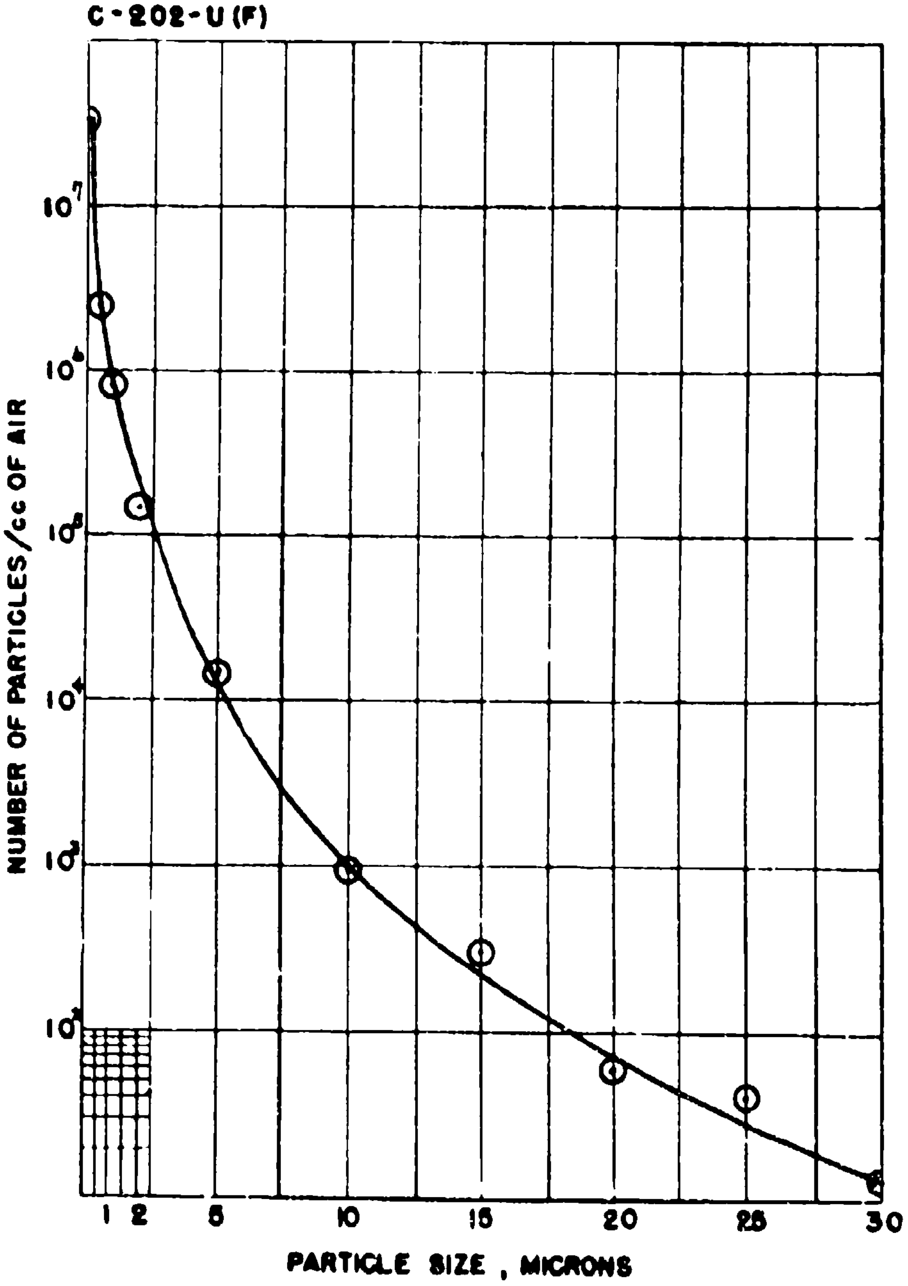

Fig. A.25 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station C-202-U

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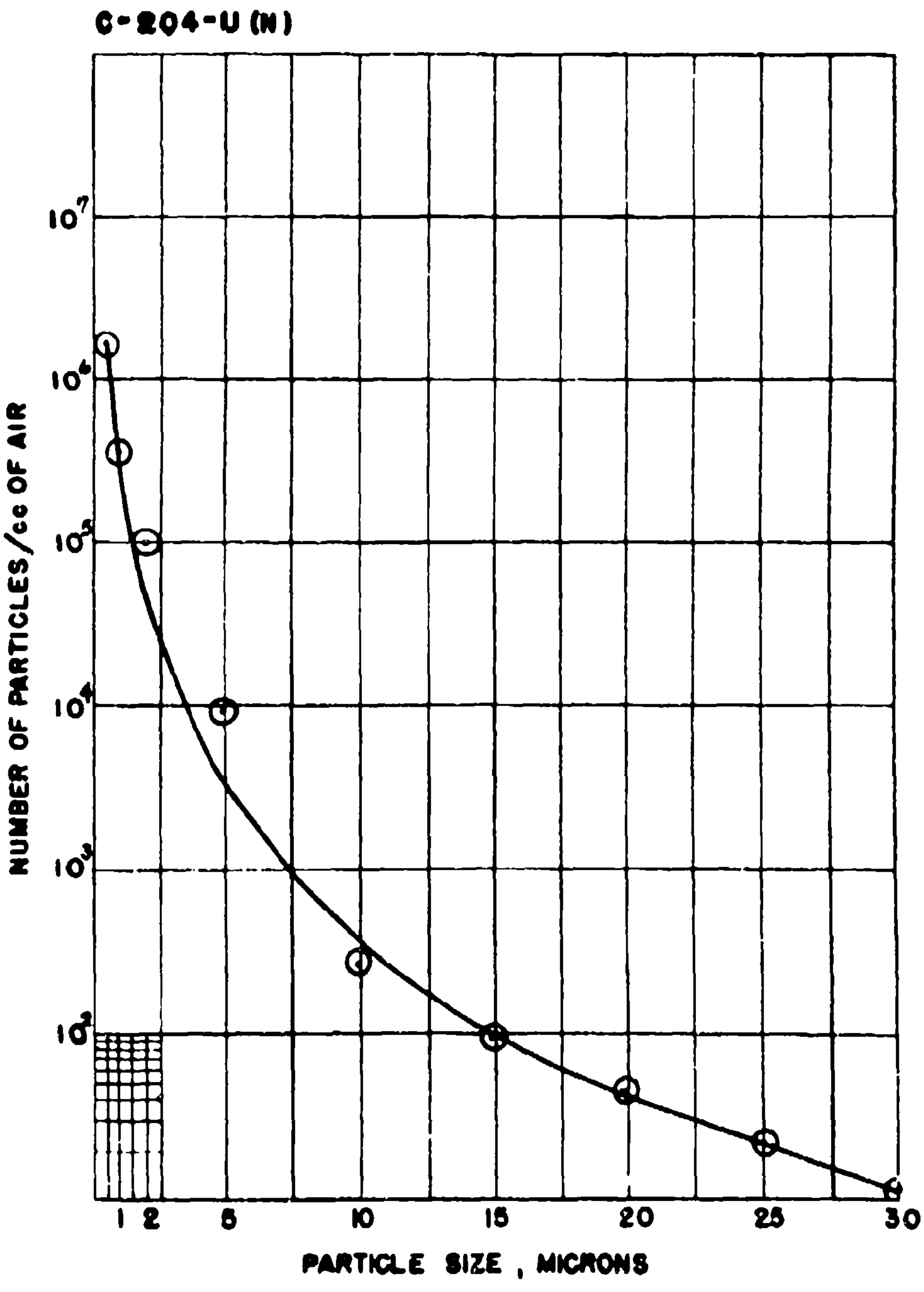

Fig. A.26 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station C-204-U

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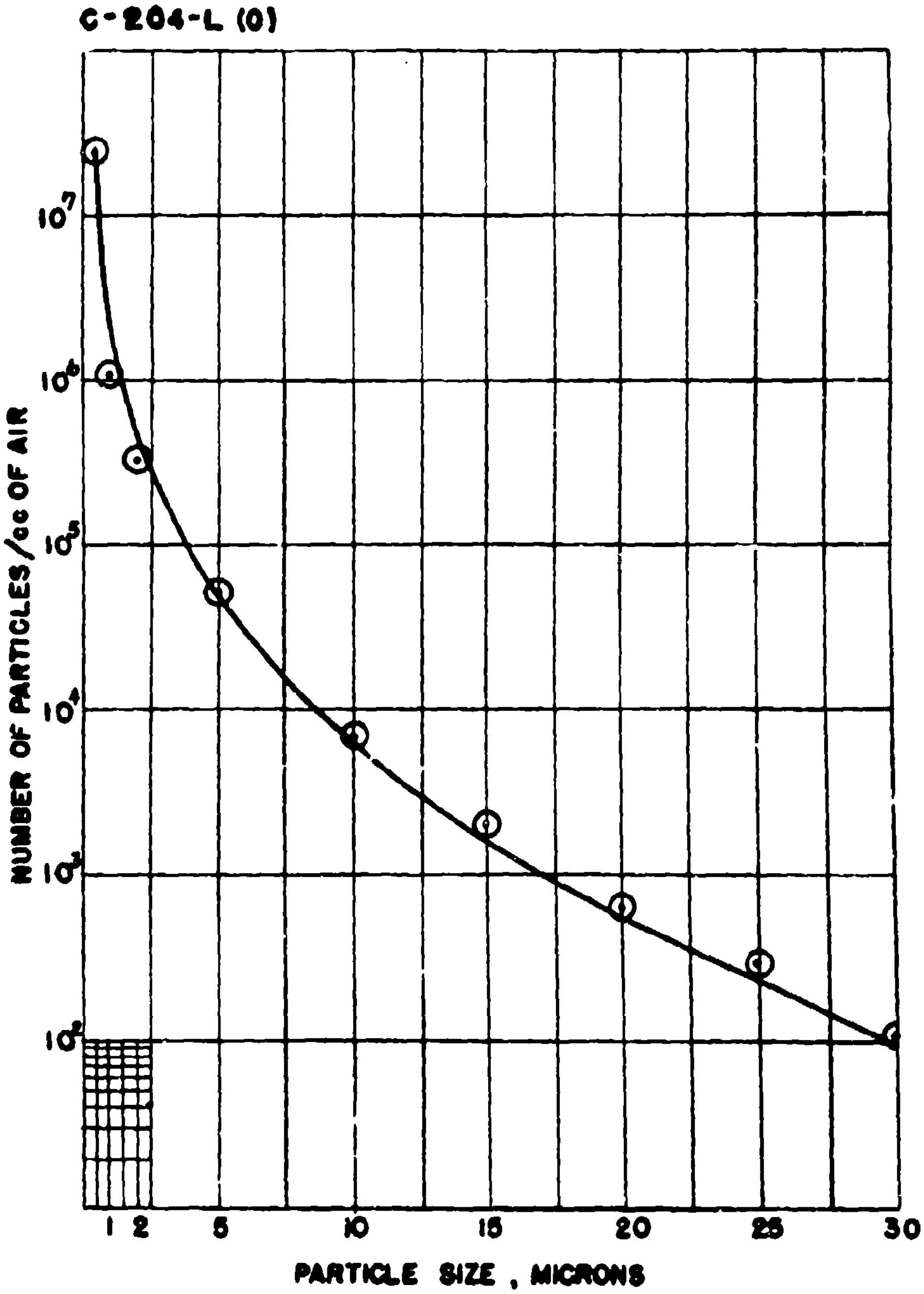

Fig. A.27 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station C-204-L

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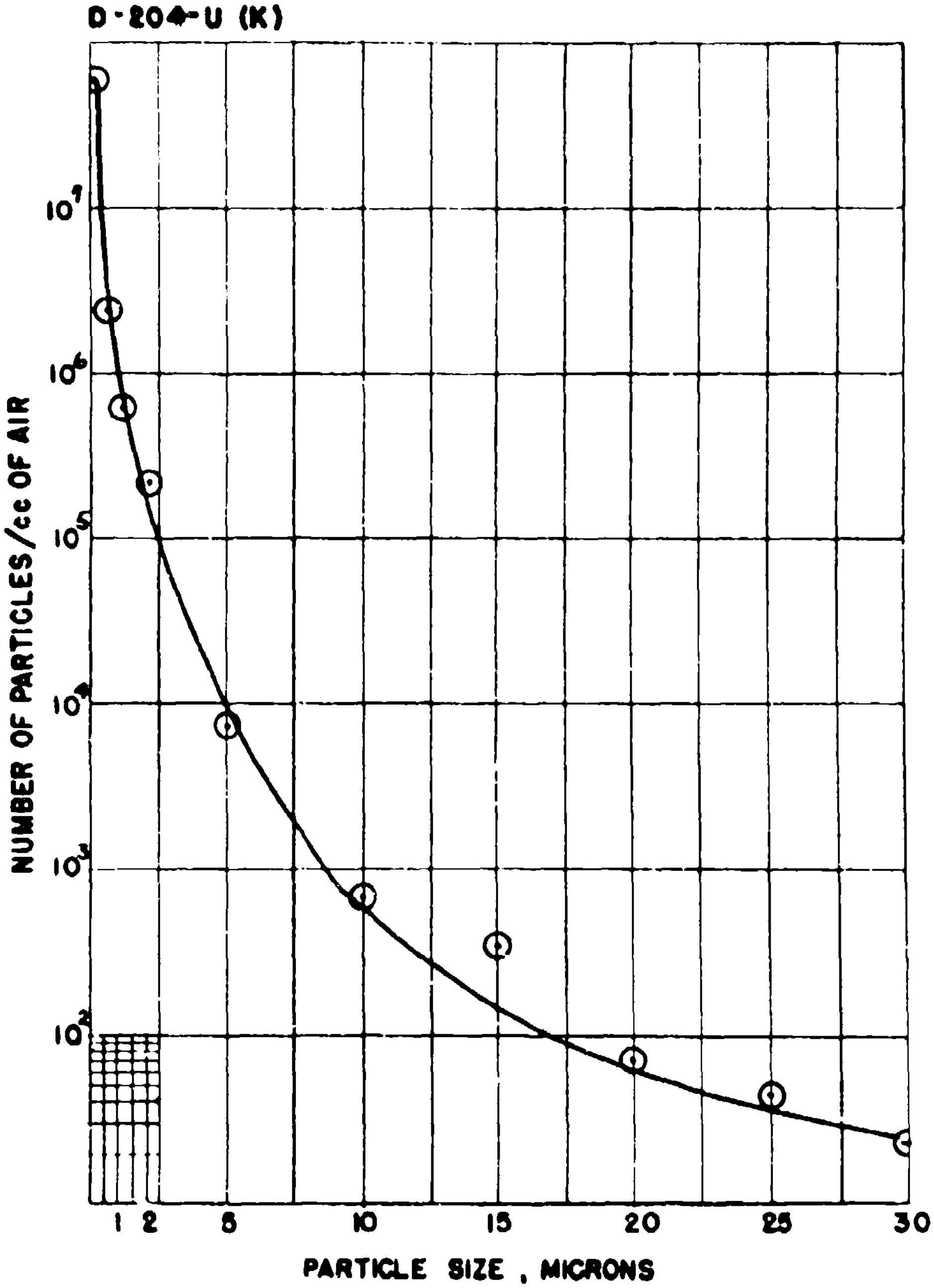

Fig. A.28 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station D-204-U

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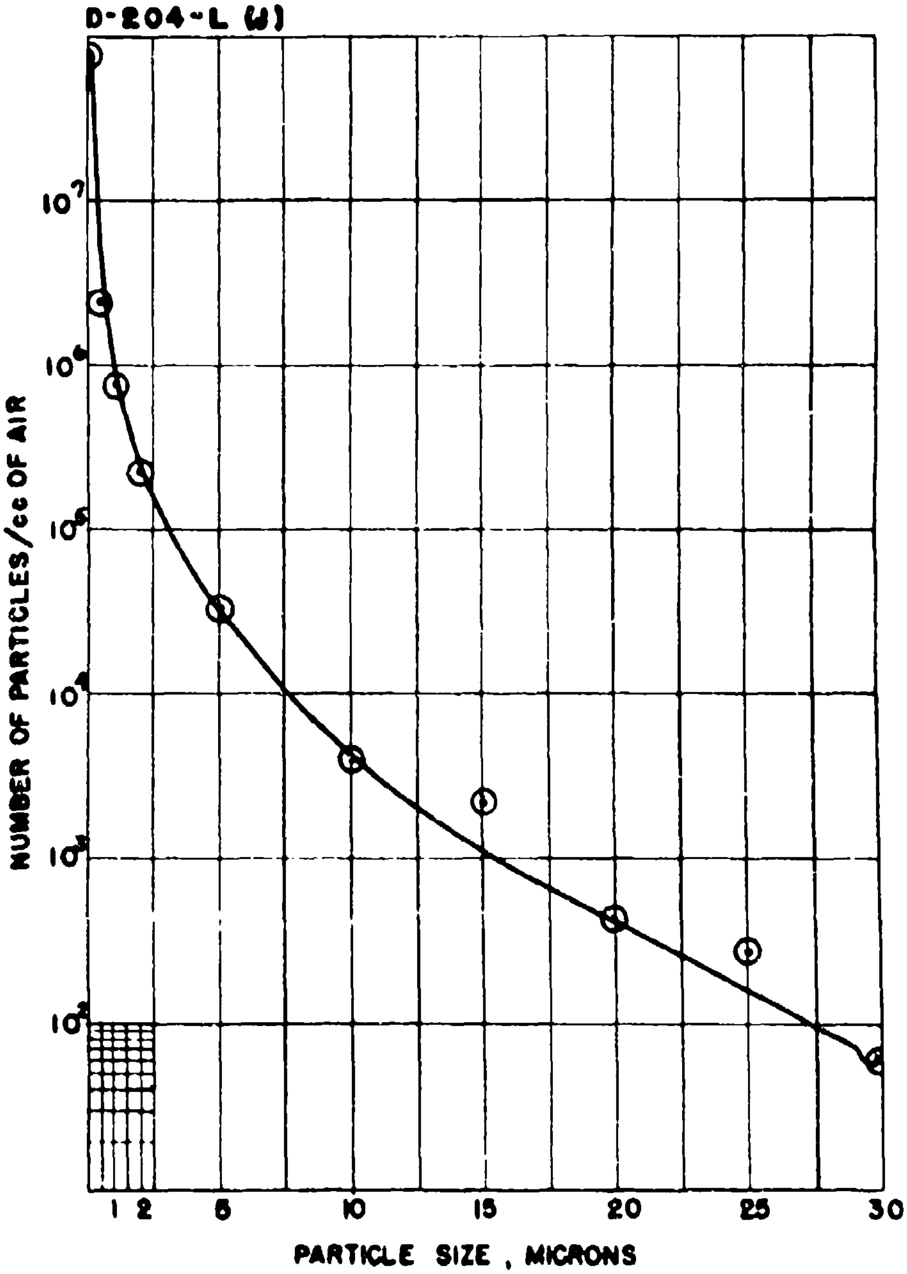

Fig. A.29 Pre-shock Dust Particle Size Distribution, Cascade Impactor, Station D-204-L

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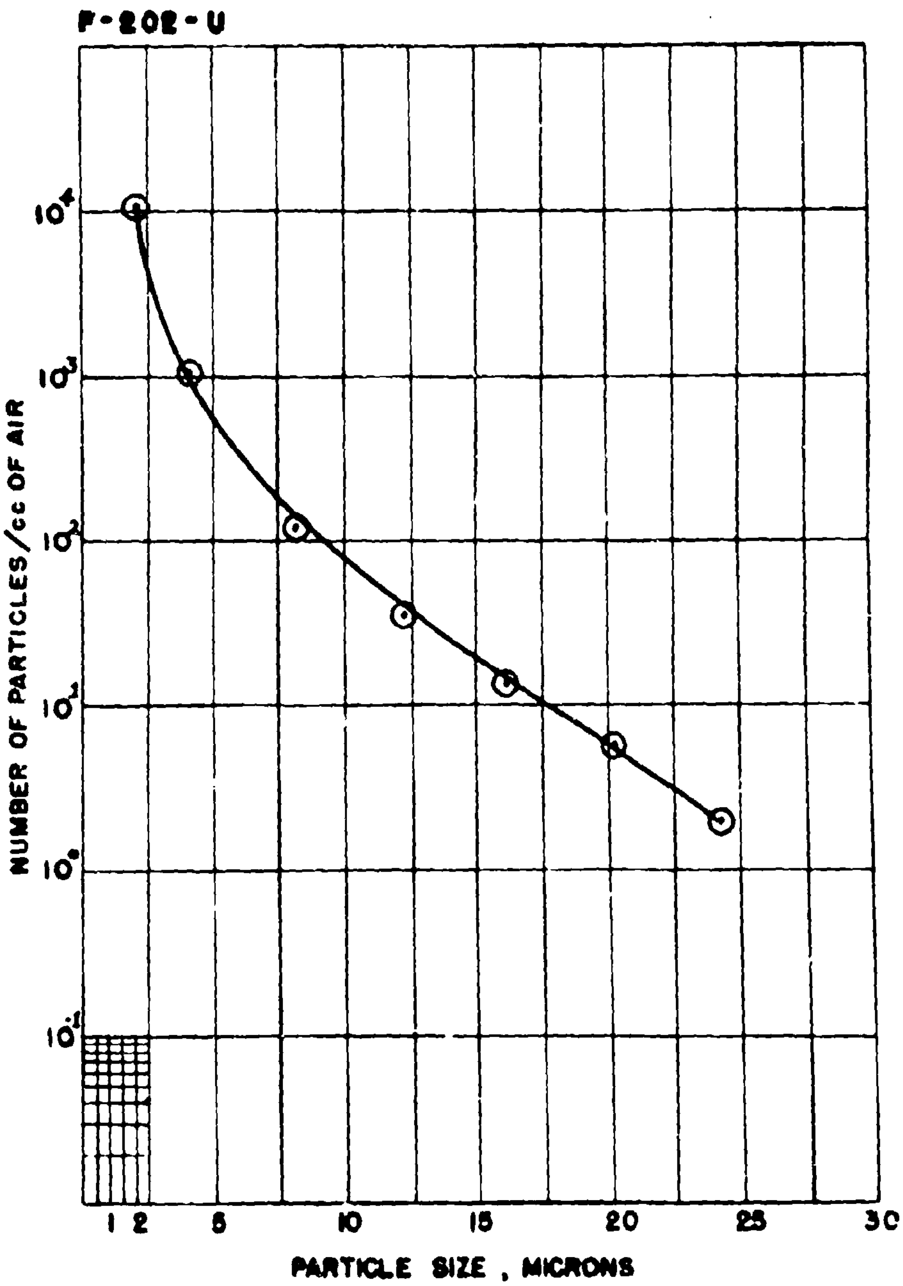

Fig. A.30 Pre-shock Dust Particle Size Distribution, Molecular Filter, Station F-202-U

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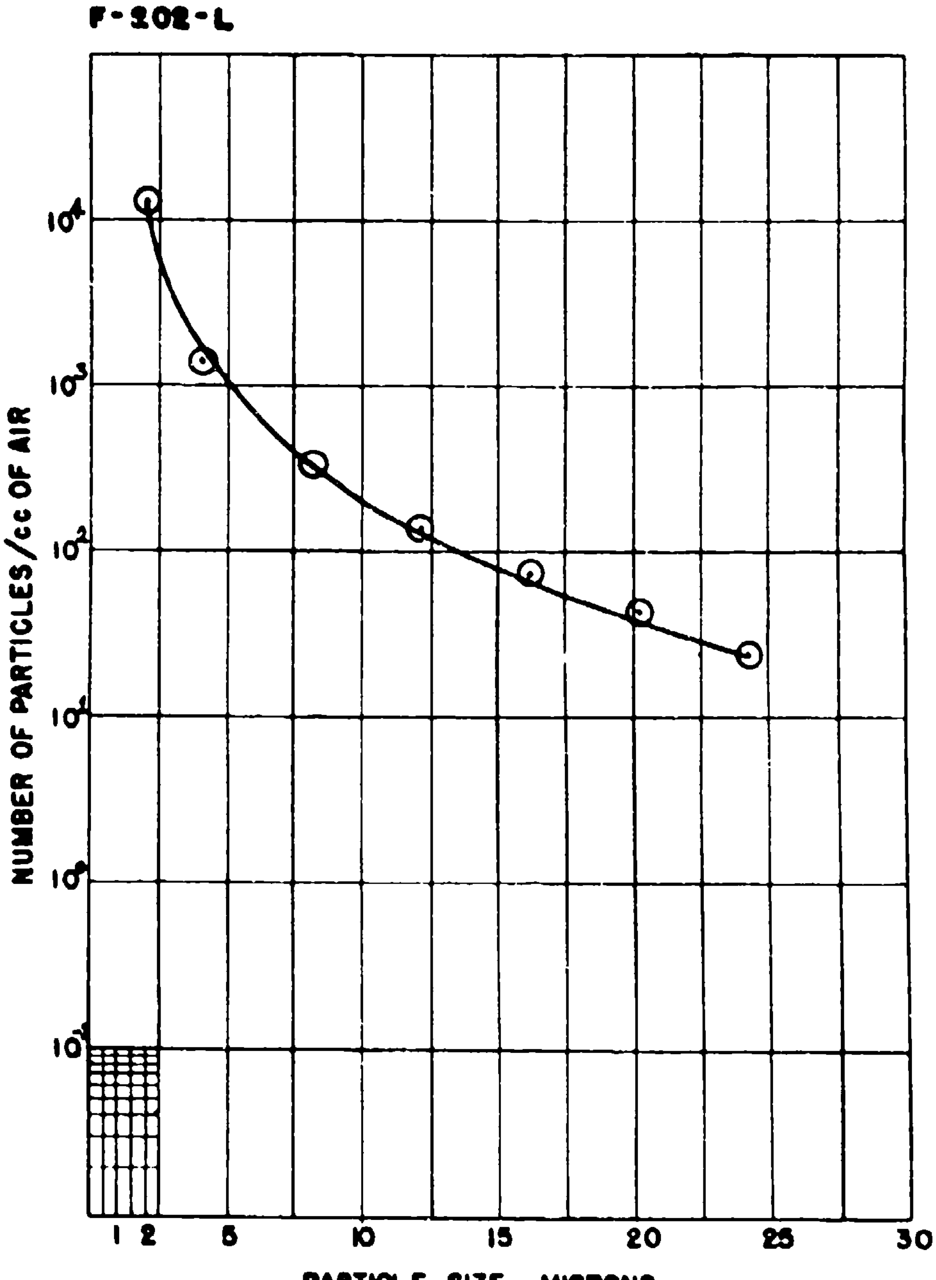

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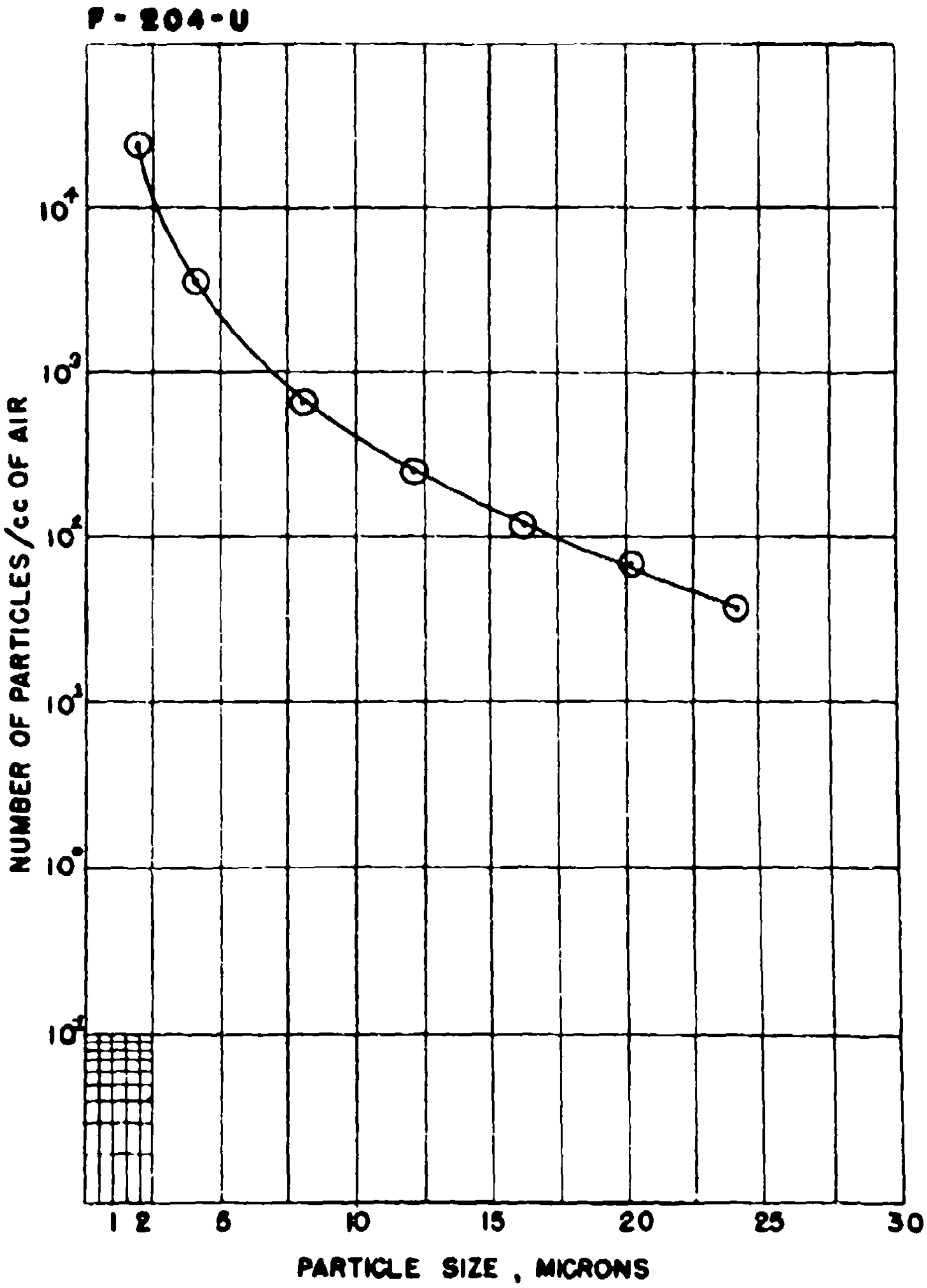

Fig. A.32 Pre-shock Dust Particle Size Distribution, Molecular Filter, Station F-204-U

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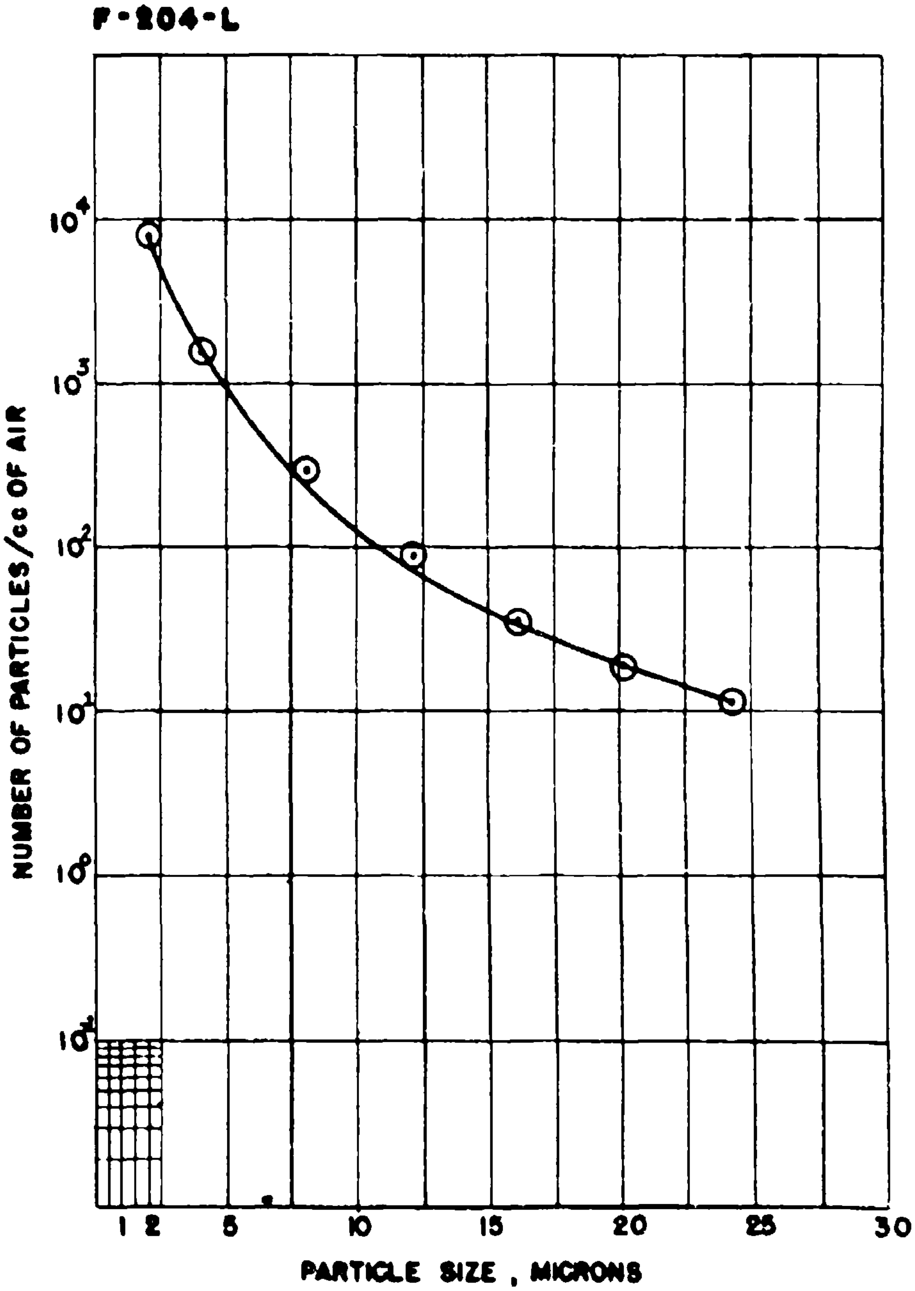

Fig. A.33 Pre-shock Dust Particle Size Distribution,
Molecular Filter, Station F-204-L

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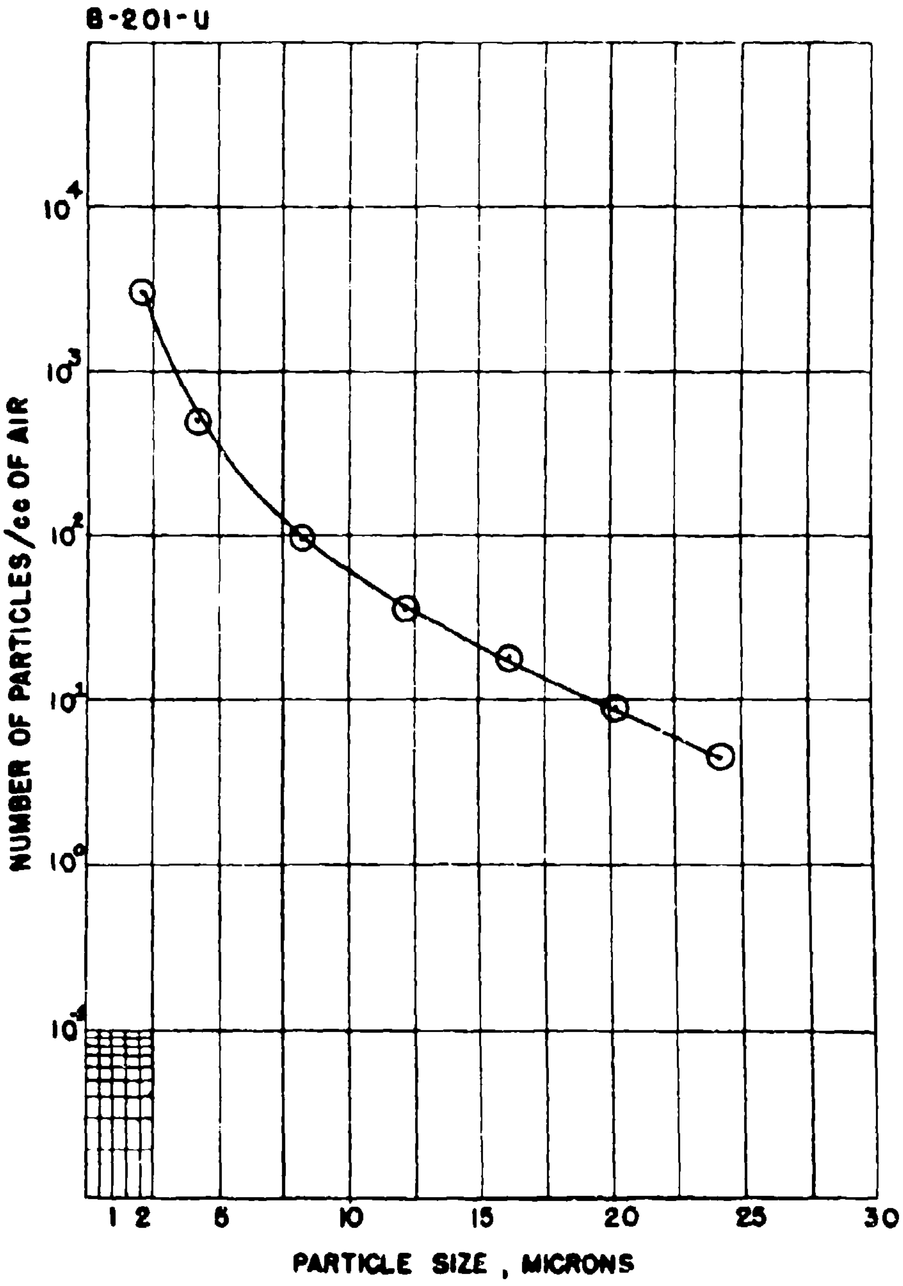

Fig. A.34 Pre-shock Dust Particle Size Distribution, Molecular Filter, Station B-201-U

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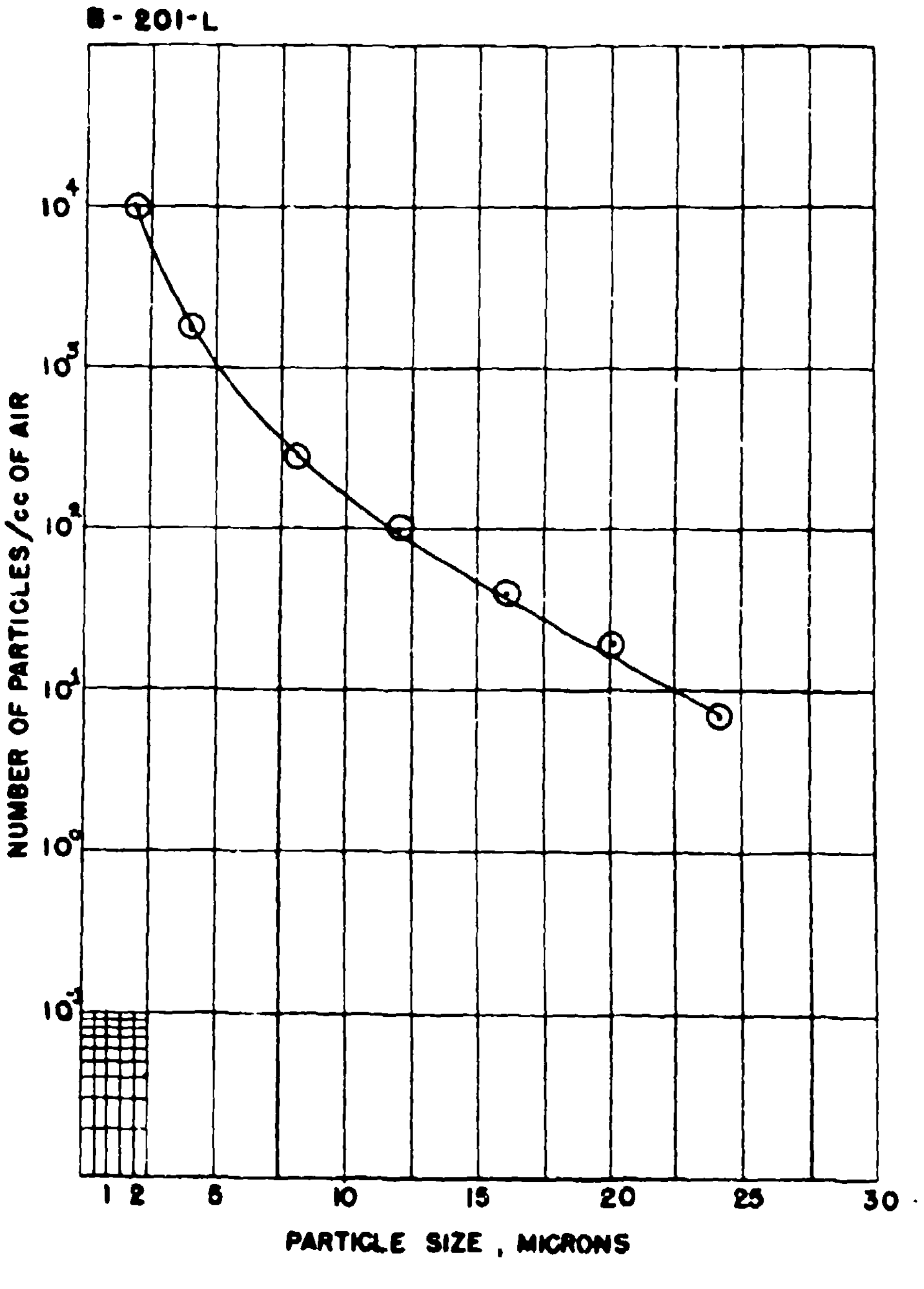

Fig. A.35 Pre-shock Dust Particle Size Distribution, Molecular Filter, Station B-201-L

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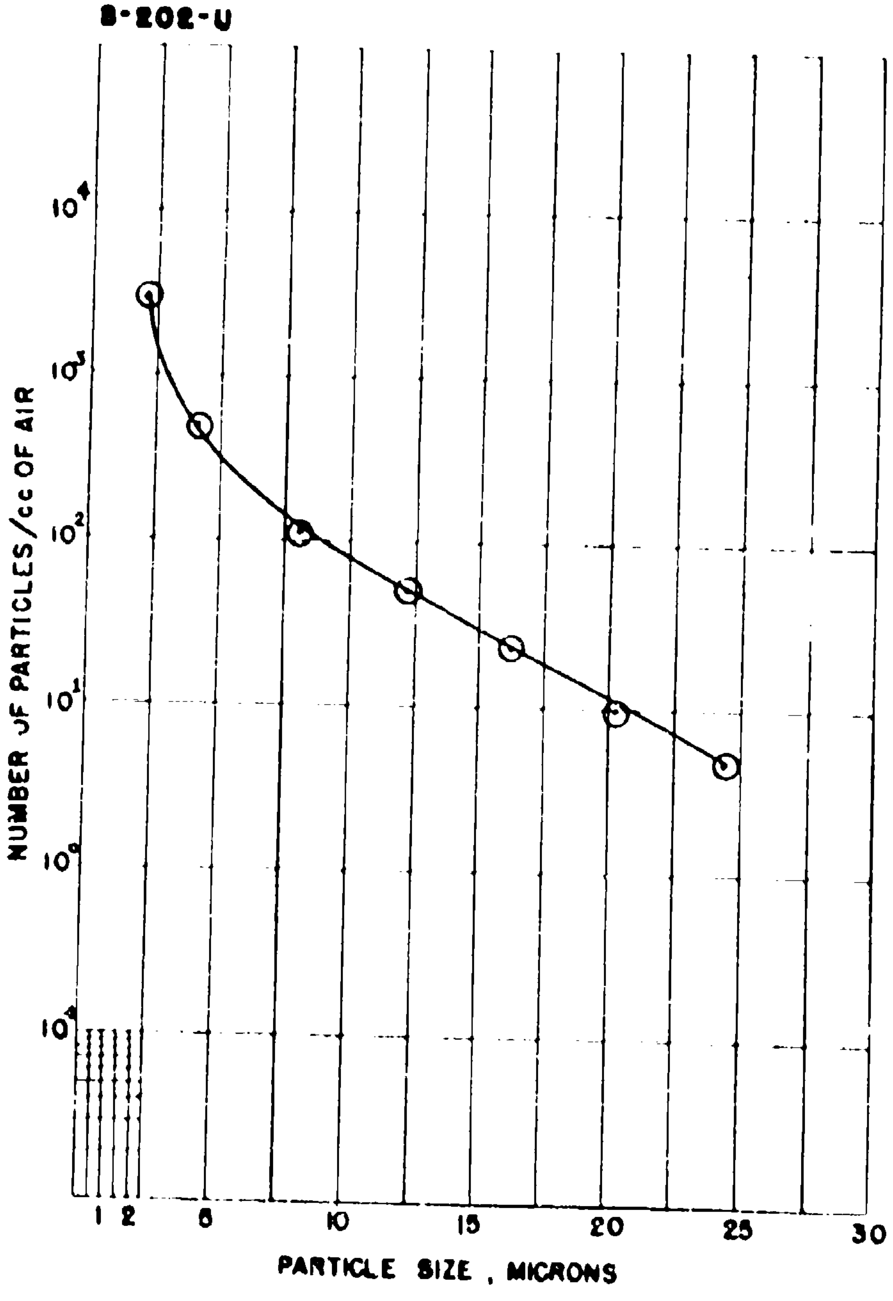

Fig. A.36 Pre-shock Dust Particle Size Distribution, Molecular Filter, Station B-202-U

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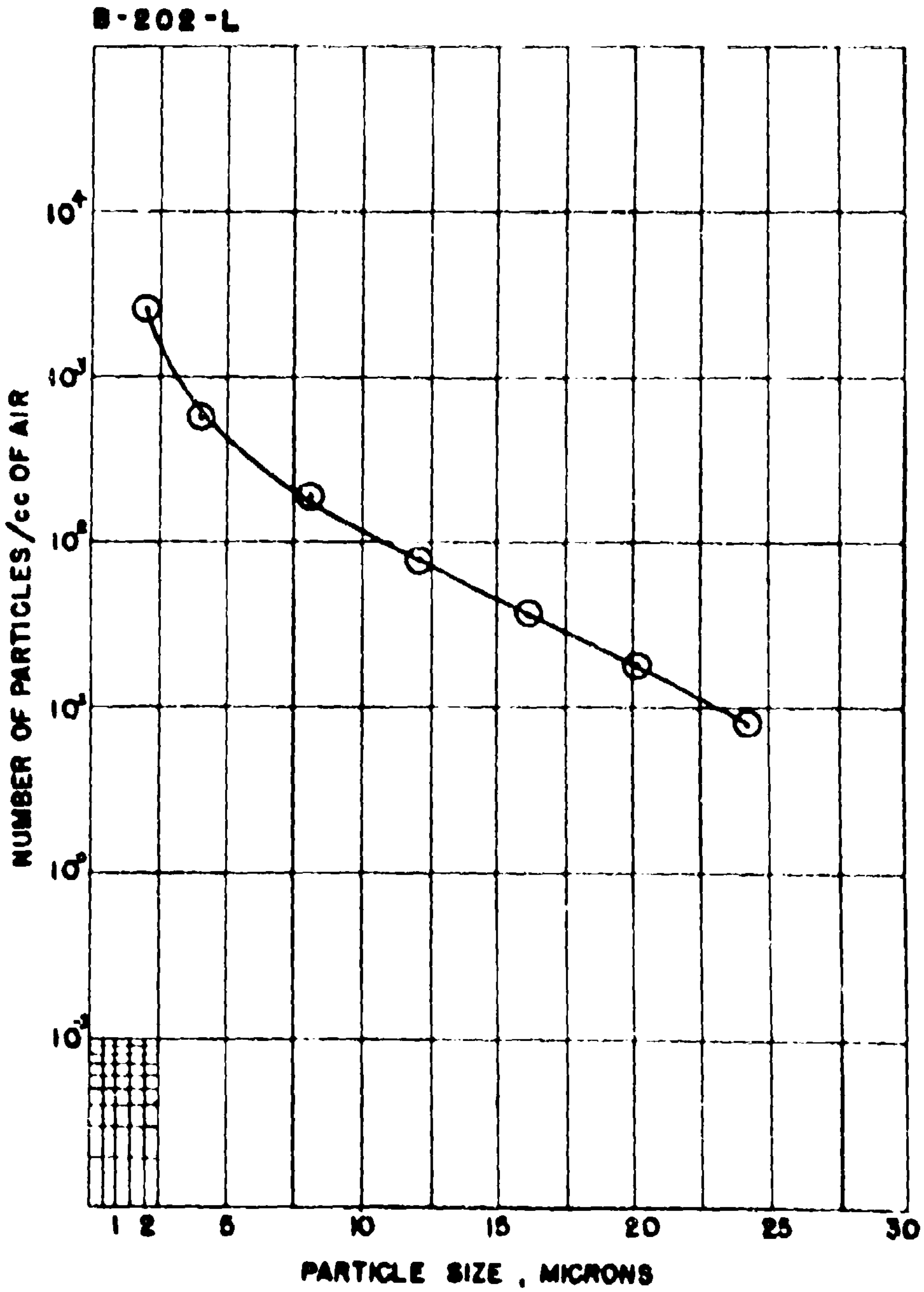

Fig. A.37 Pre-shock Dust Particle Size Distribution, Molecular Filter, Station B-202-L

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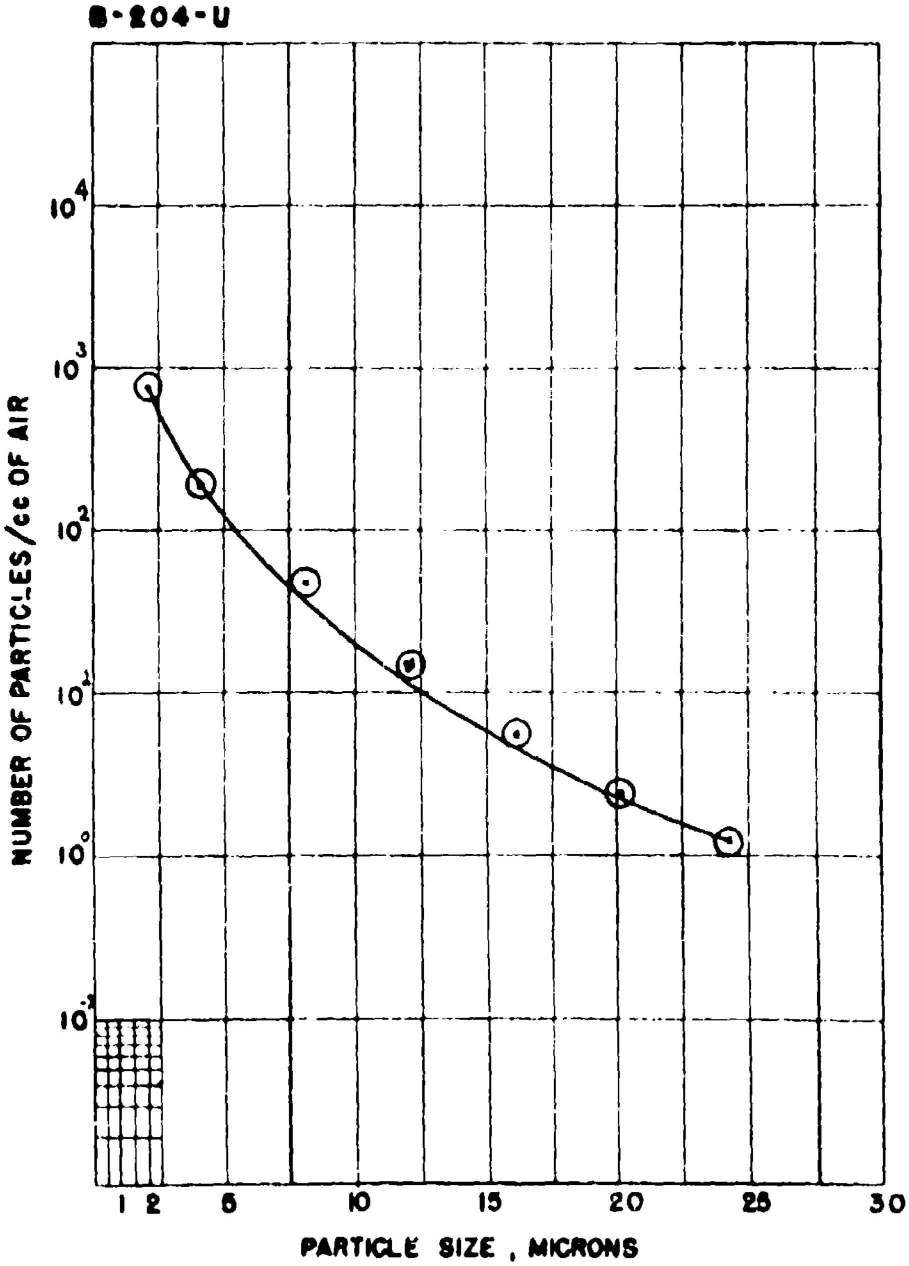

Fig. A.38 Pre-shock Dust Particle Size Distribution, Molecular Filter, Station B-204-U

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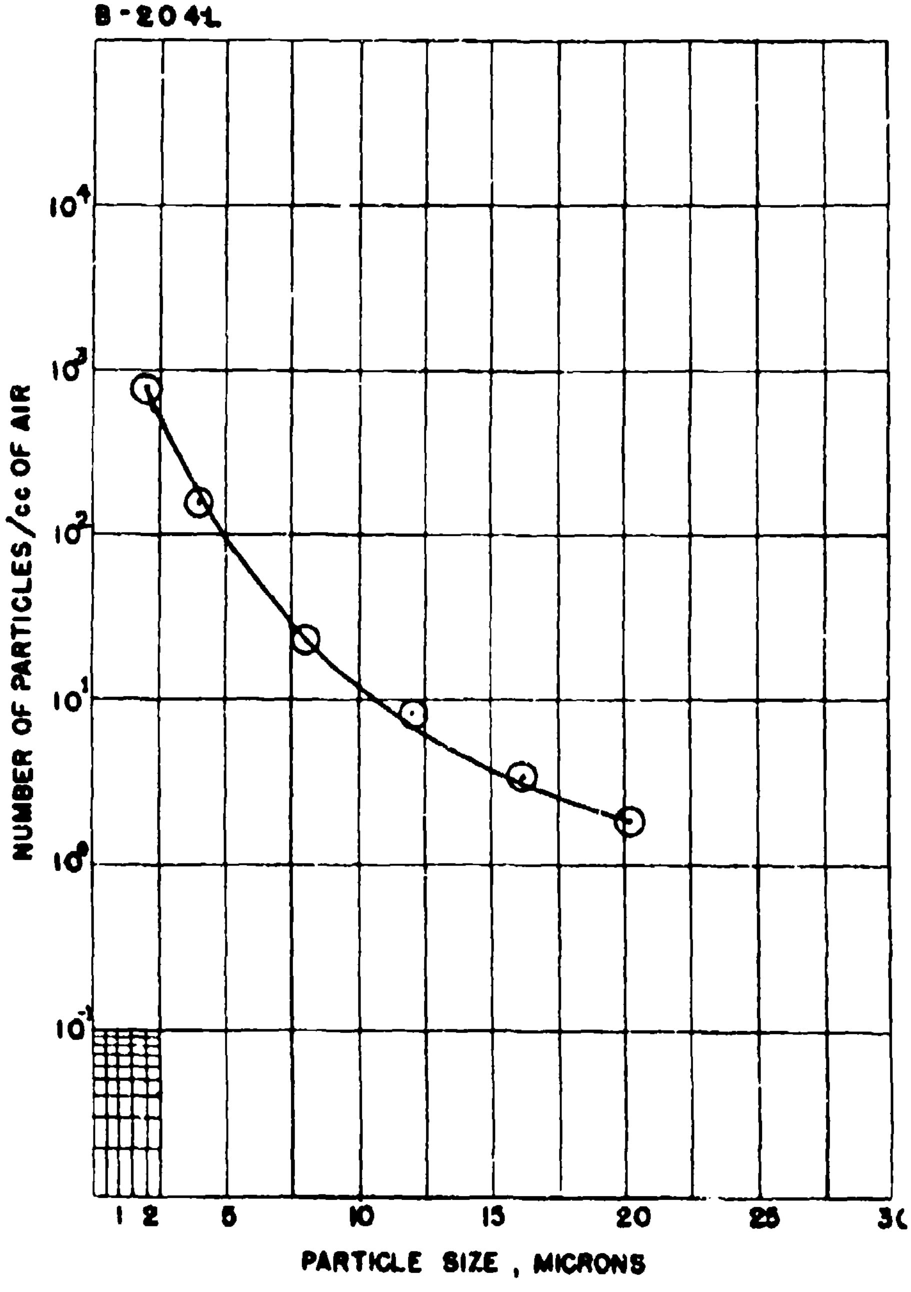

Fig. A.39 Pre-shock Dust Particle Size Distribution, Molecular Filter, Station B-204-L

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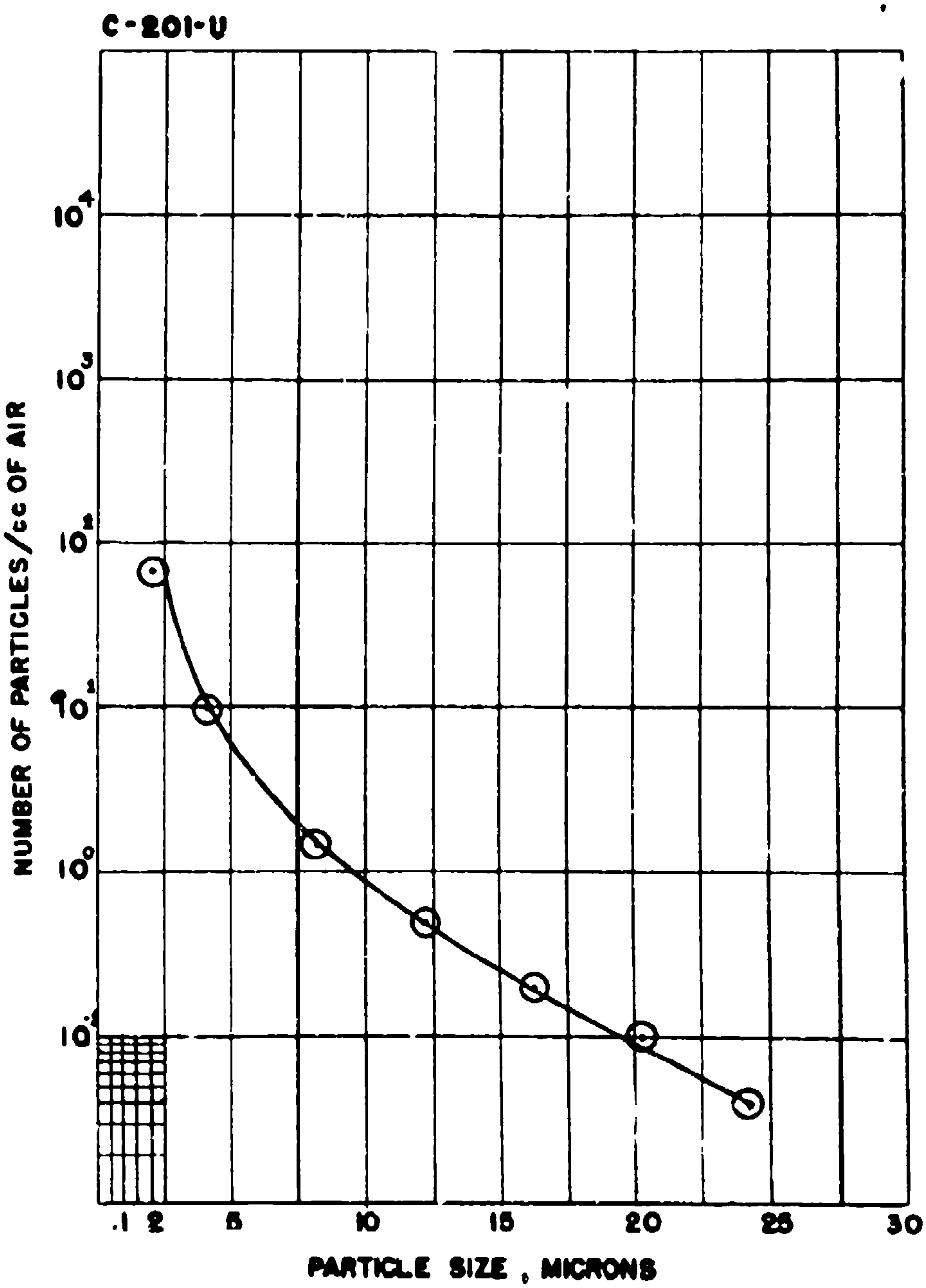

Fig. A.40 Pre-shock Dust Particle Size Distribution, Molecular Filter, Station C-201-U

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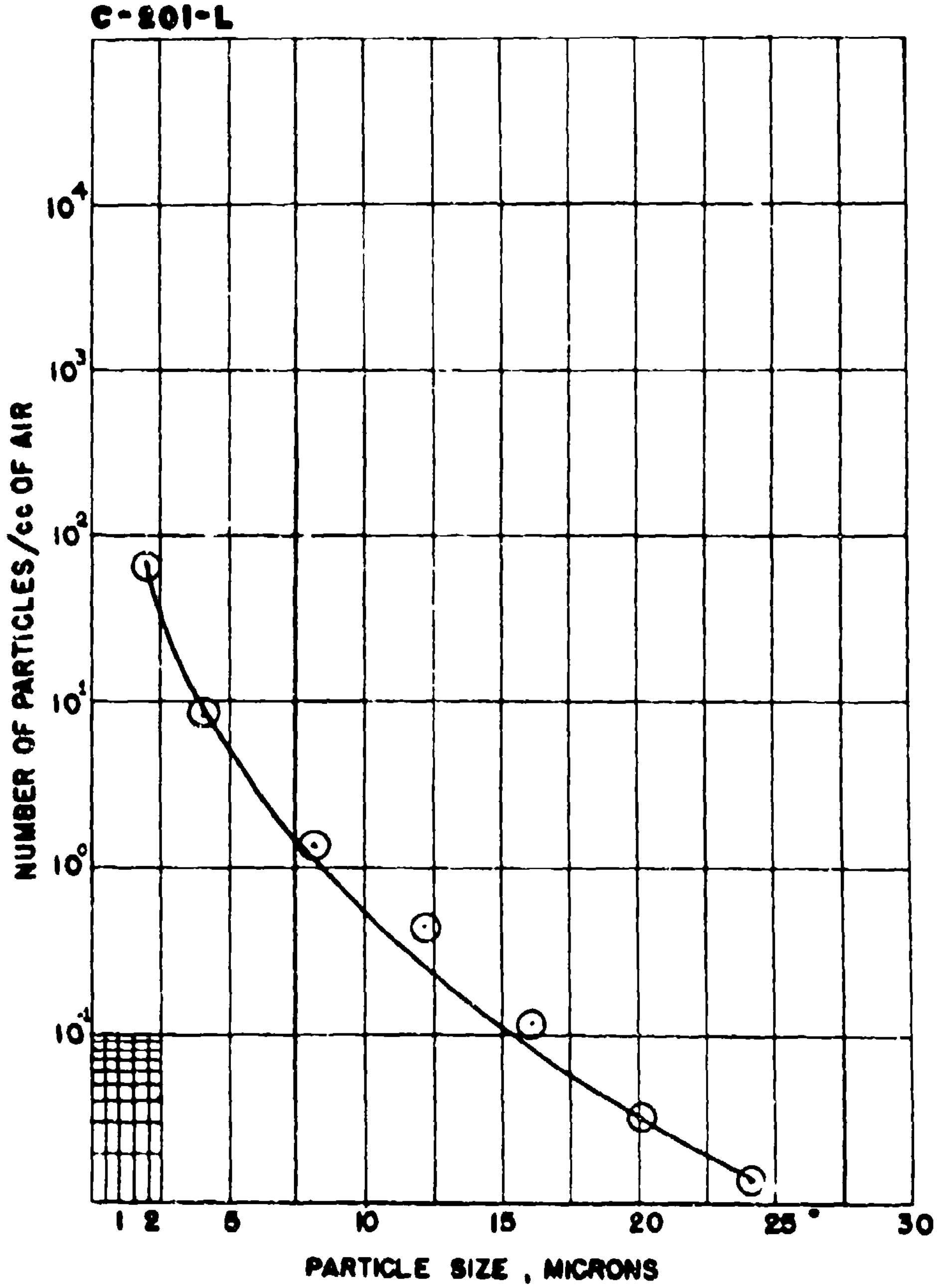

Fig. A.41 Pre-shock Dust Particle Size Distribution,
Molecular Filter, Station C-201-L

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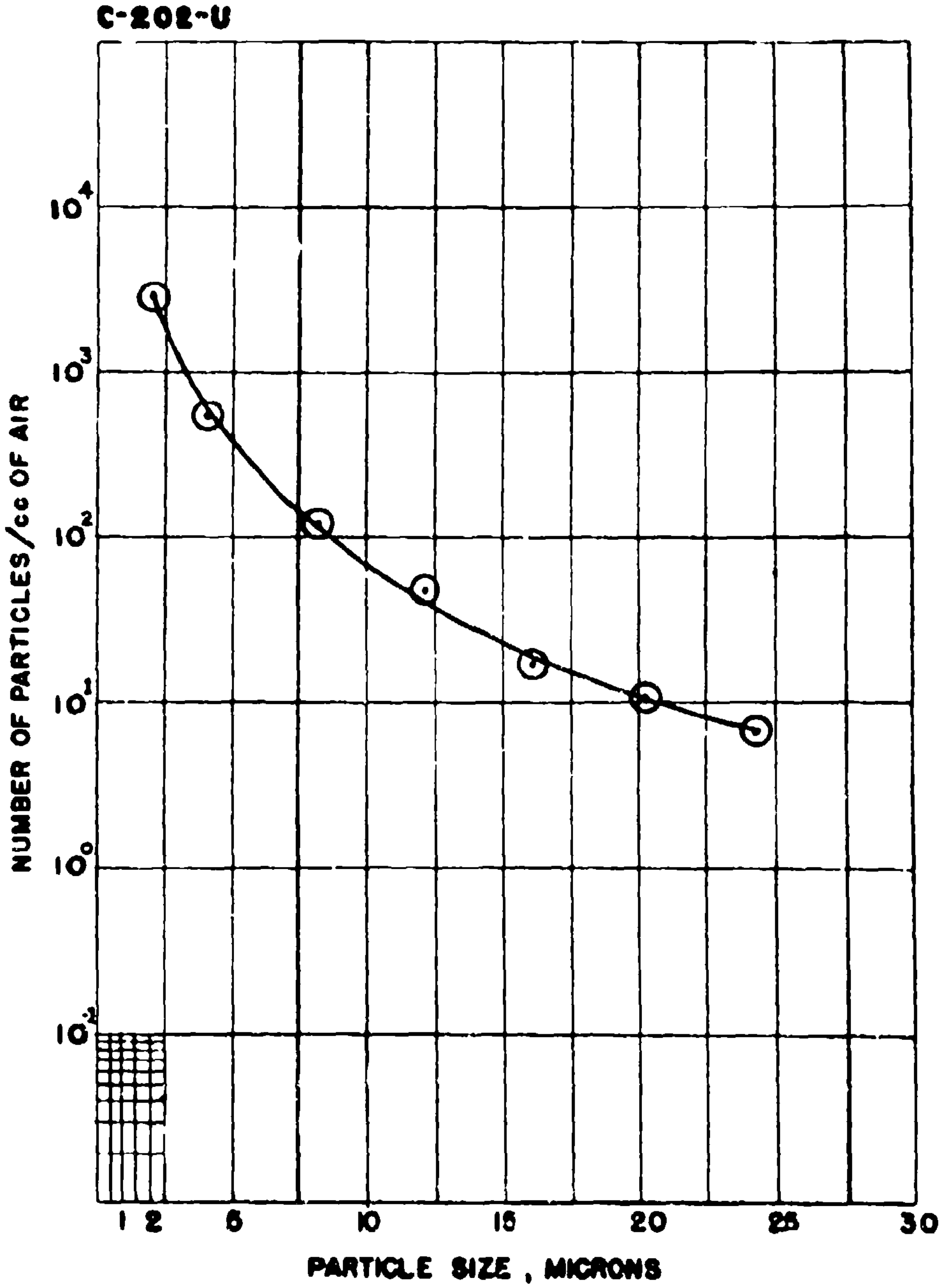

Fig. A.42 Pre-shock Dust Particle Size Distribution, Molecular Filter, Station C-202-U

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C-202-L

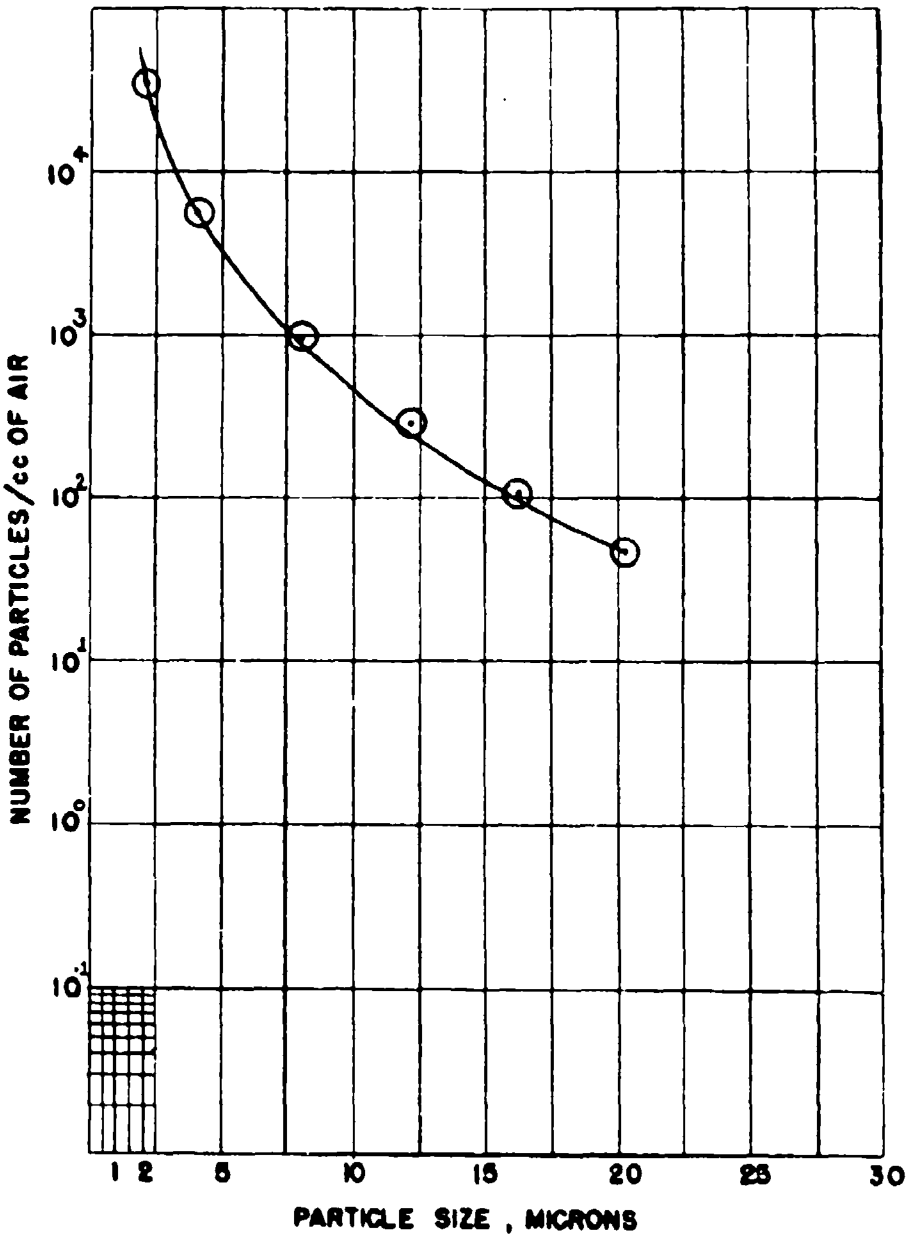

Fig. A.43 Pre-shock Dust Particle Size Distribution, Molecular Filter, Station C-202-L

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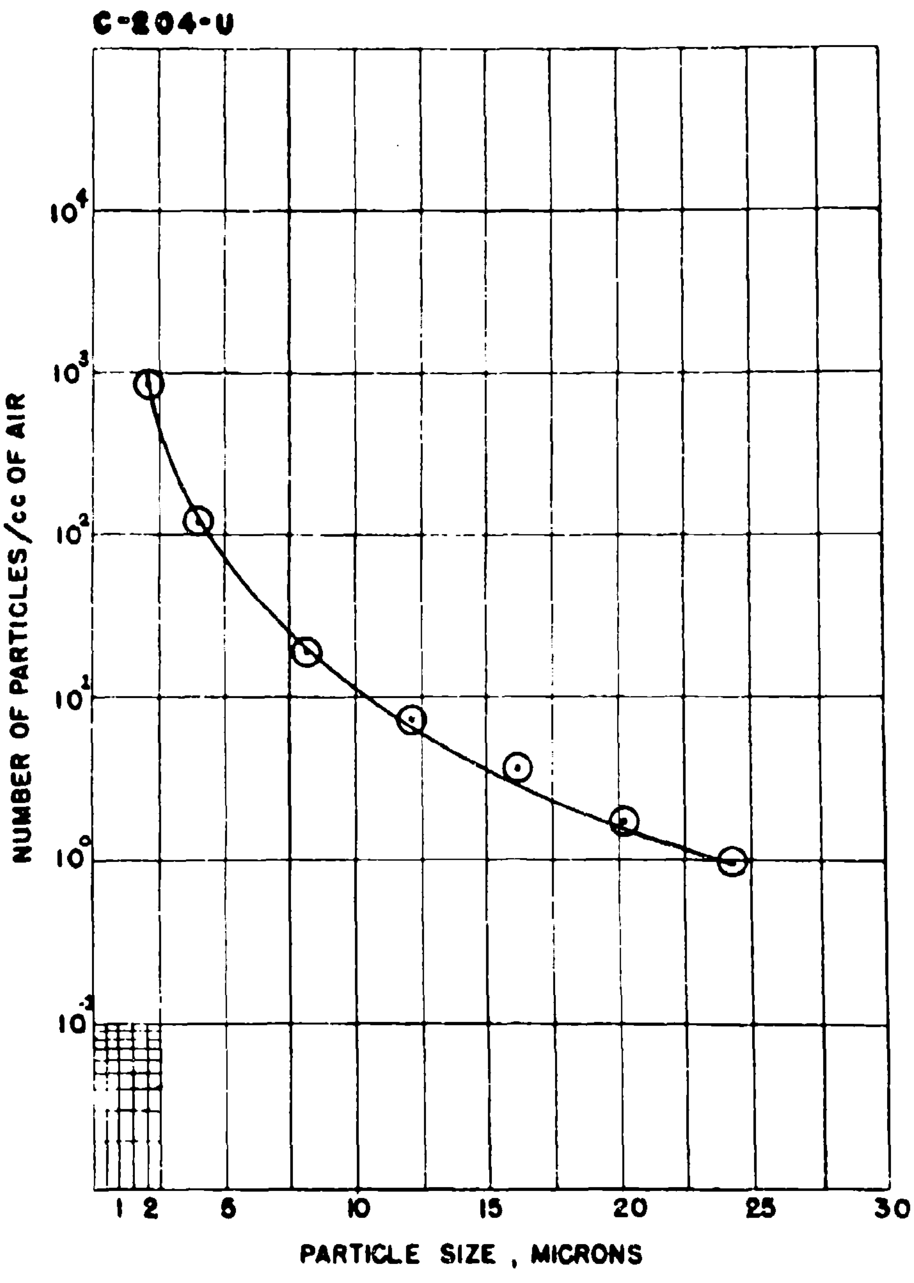

Fig. A.44 Pre-shock Dust Particle Size Distribution, Molecular Filter, Station C-204-U

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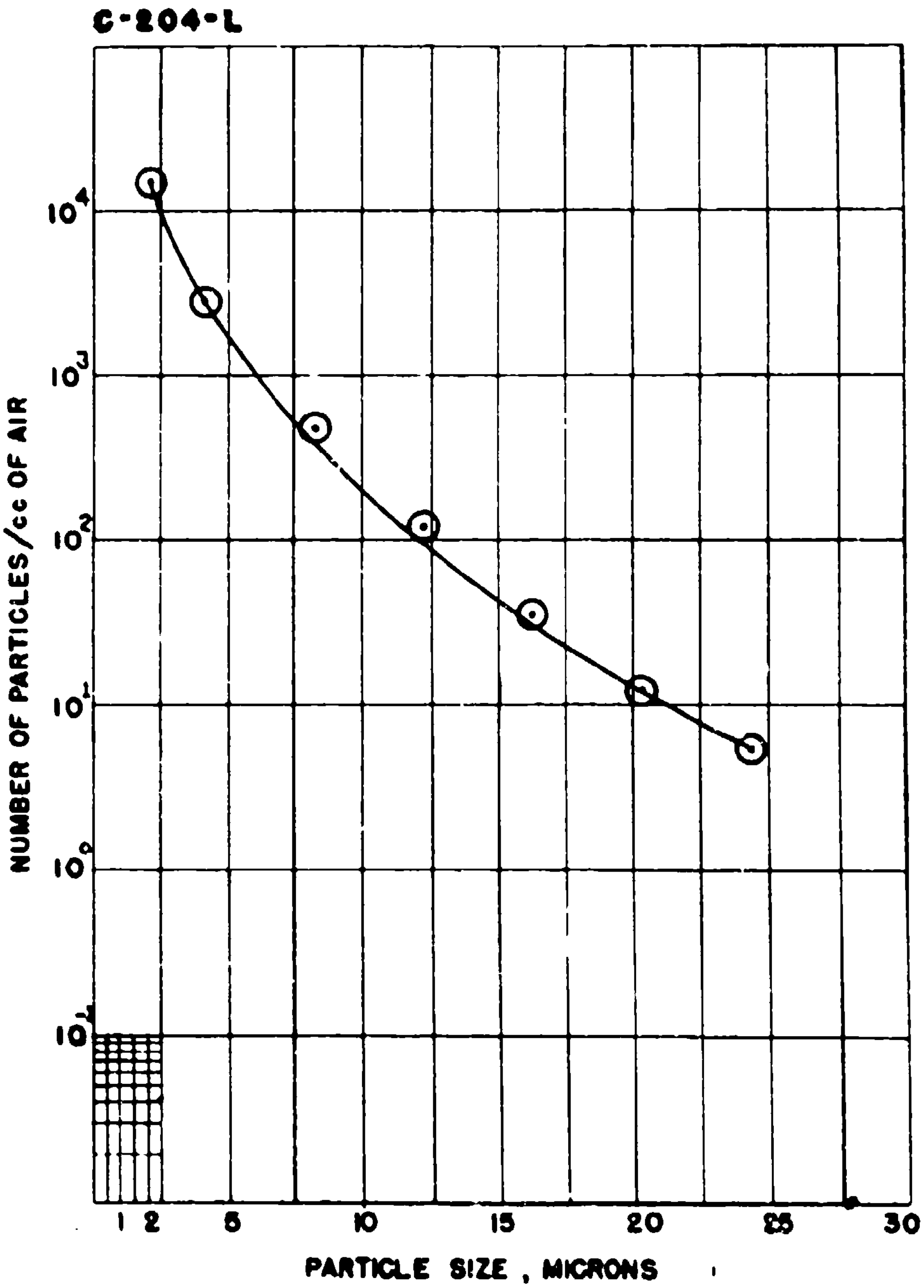

Fig. A.45 Pre-shock Dust Particle Size Distribution, Molecular Filter, Station C-204-L

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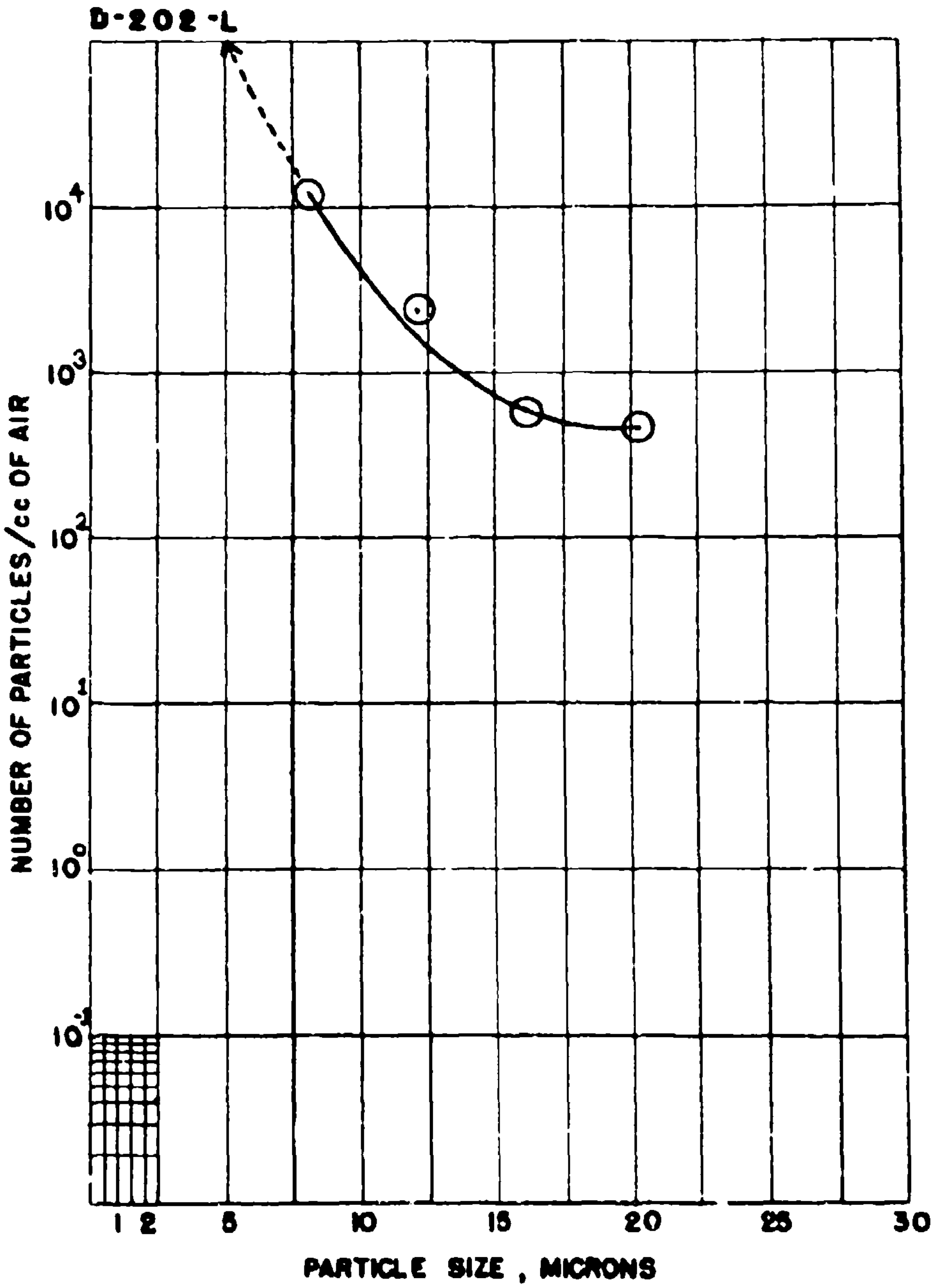

Fig. A.46 Pre-shock Dust Particle Size Distribution, Molecular Filter, Station D-202-L

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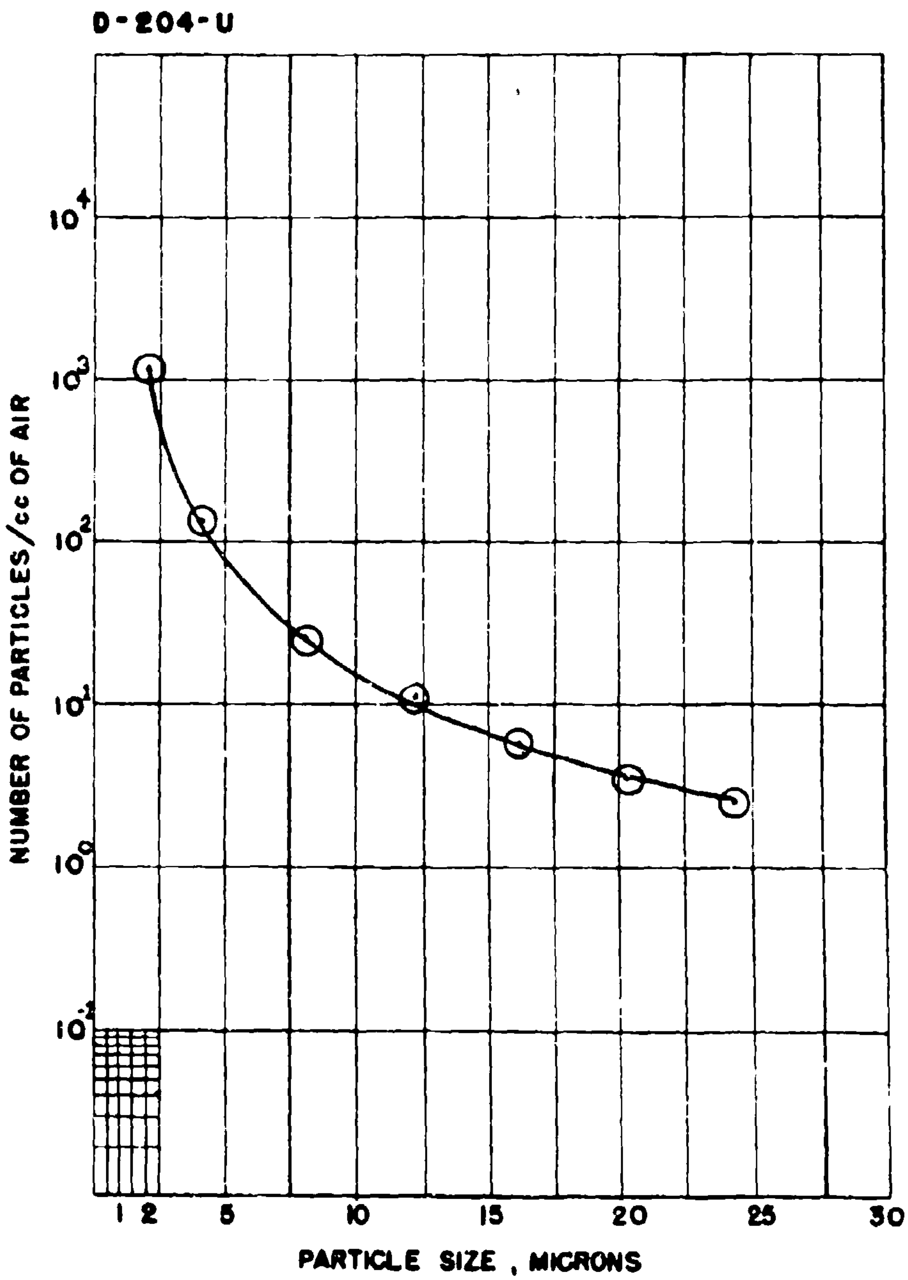

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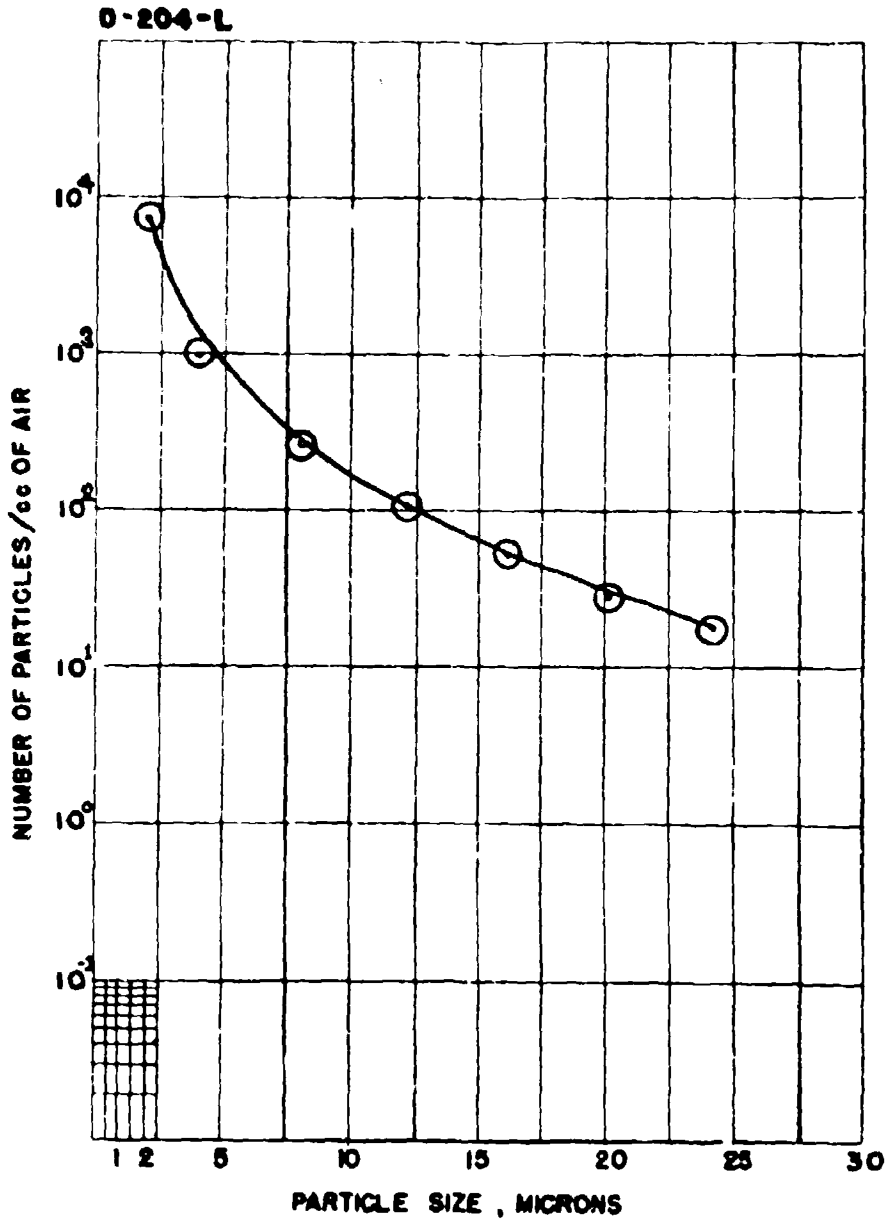

Fig. A.48 Pre-shock Dust Particle Size Distribution, Molecular Filter, Station D-204-L

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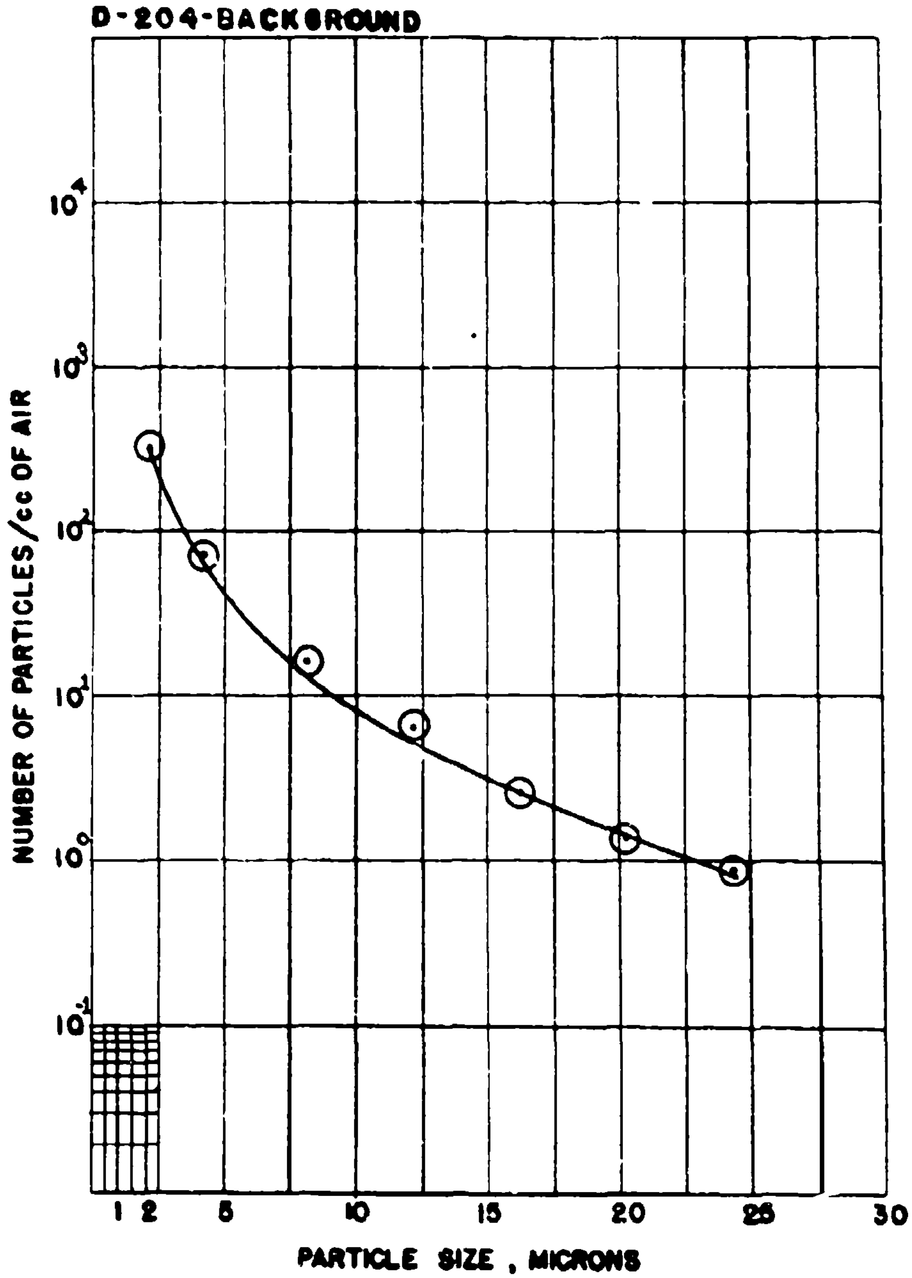

Fig. A.49 Background Dust Particle Size Distribution, Molecular Filters, Station D-204-B

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APPENDIX B

DAMAGE TO STATIONS

B.1 EFFECT OF SHOTS

No damage was caused by the first three shots; however, the fourth shot caused almost completely demolished stations 7-201 and 7-202.

B.2 STATION 7-201

At station 7-201, the sampling box at the 10 ft. level was moved 50 ft. to the rear of the foundation and the impactor and filter sampler broken. The ground level box stayed on its foundation and the samplers remained on their mountings, but samples could be obtained. Both molecular filters were apparently burned up by thermal radiation. The canisters were blown away from the upper samplers. The lower canister paper was scorched.

B.3 STATION 7-202

At station 7-202, the upper sampling box was blown about 300 ft. from the foundation. The only usable sample obtained at this station was on the molecular filter at ground level.

At both stations, the aluminum covering the boxes and guy wires disappeared, presumably by burning. Also, the pressure actuated microswitch supports were bent to the ground.

B.4 STATION 7-204

At station 7-204, some aluminum sheeting was stripped off the guy wires. No other damage was done.

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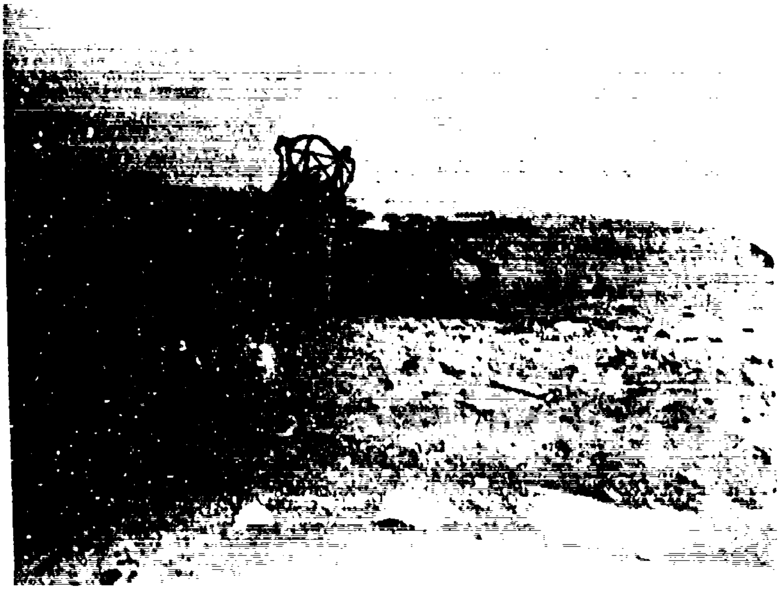

Fig. B.1 Station 7-201 After Shot 4

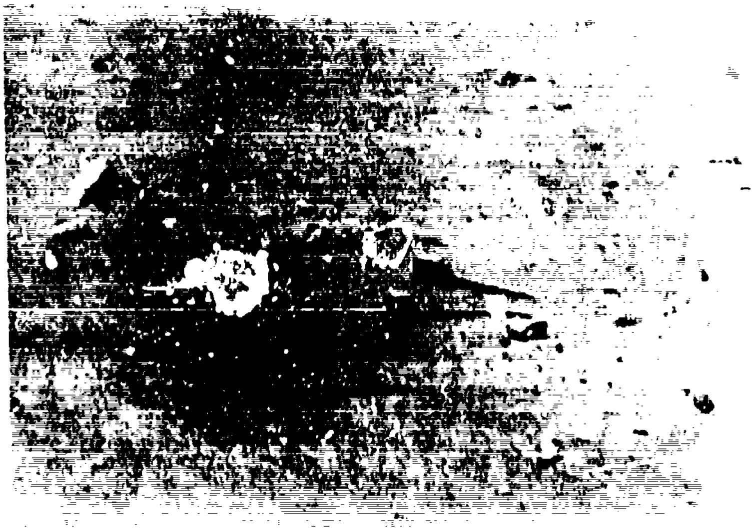

Fig. B.2 Station 7-201 Blast Closure Microswitches After Shot 4

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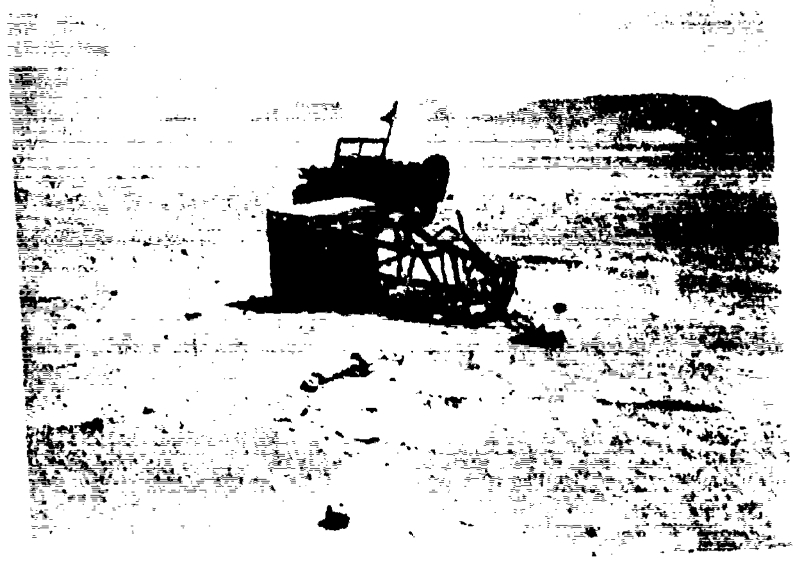

Fig. B.3 Station 7-202 Tower and Sampling Equipment After Shot 4

Fig. B.4 Station 7-204 After Shot 4

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APPENDIX C

DETAILS OF CASCADE IMPACTOR ASSEMBLY

For Shot 1, the first and second jets of the impactor were loaded with plain plastic slides, however, for the rest of the shots, plain glass slides were used in the first and second jets because of difficulties encountered in cleaning the plastic slides. The third and fourth jets were loaded with plastic slides. Into each slide, Figure C.1, are fastened two electron microscope screw-cap-screen assemblies. The 200-mesh screen supported a formvar film. The fifth jet of each impactor was loaded with a plastic slide, which contained a formvar film in an electron microscope screw-cap-400-mesh screen assembly. This use of 400-mesh screen and formvar film is new. The formvar film was used because it is very tough and apparently unaffected by the electron beam in the electron microscope.

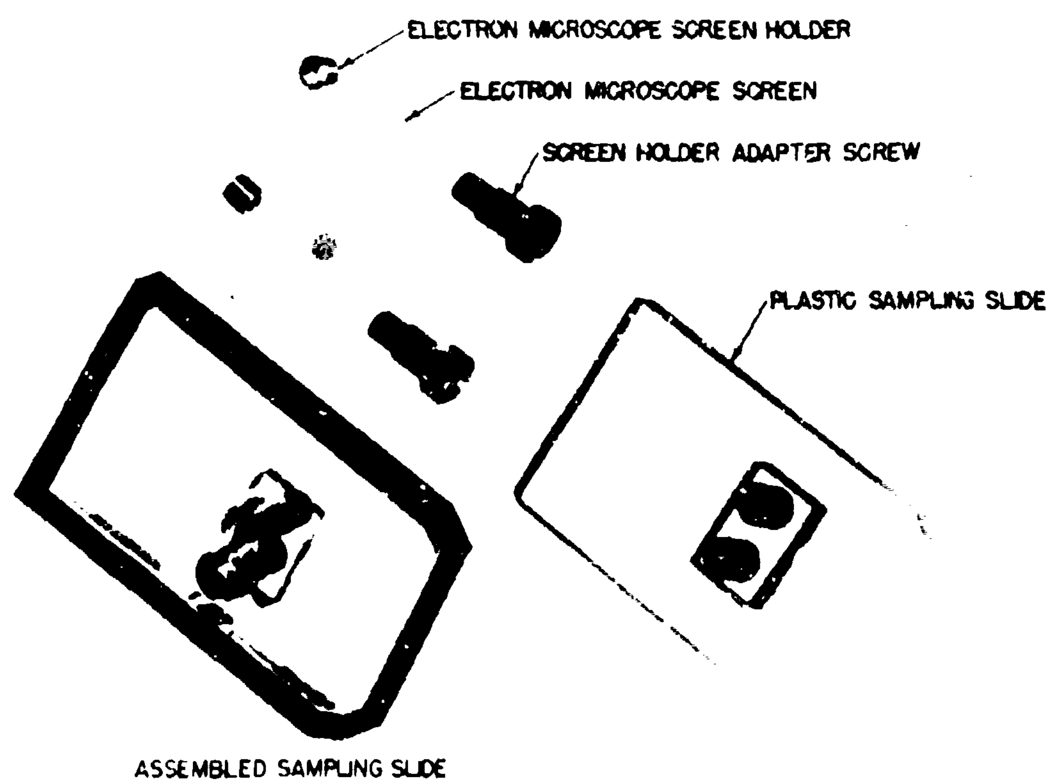

Fig. C.1 Cascade Impactor Plastic Slide Assembly

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